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ON THE TEMPERATURE OF THE SUN.*

By HUGO BILGRAM.

Several years ago an article came to my notice stating the estimates of the temperature of the sun, by different authors. These figures varied between about 4,000 and 4,000,000 degrees, Centigrade. It is not difficult to conclude that such a difference cannot be attributed to errors of observation, and that some of the theories on which those estimates were based must have been erroneous.

Having some inclination for such studies I tried to find a method myself for making an estimate, and during these studies a series of very interesting points suggested themselves to my mind that were new to me, and may be so in part to others. The following is a brief statement of these studies, and of the results arrived at.

We receive heat from the sun by radiation exclusively, and the laws of radiant heat were the only resort for the intended investigations.

It is well known that if an object of one temperature is surrounded by walls of another temperature, an exchange of heat will take place by radiation, until the temperatures of both the inclosed object and the

* The above paper was read at the stated meeting of the Institute, held May 17, 1876. As it anticipates some conclusions reached in recent investigations, it has been thought desirable to publish it.—H. B.

surrounding walls are equalized. [Theoretically the temperatures will never be equalized, just as the branch of a hyperbola never meets its asymptote, but after a longer or shorter time the difference will become practically imperceptible.]

The following ideal experiments are supposed to be made in a vacuum to exclude the effect of conduction and convection of heat.

If a globular body (see Fig. 1) is inclosed centrally by two hemispherical walls of different, but permanent temperatures, a continual exchange of heat will take place. It will receive heat from the warmer side, and give off heat to the colder side. Supposing the central body be a perfect conductor of heat, its ultimate temperature will depend on two conditions; on the temperature of each of the hemispheres, and on the condition of their radiating surfaces.

Fig. 1

In text-books the radiation of heat is stated to be in direct proportion to the temperature and to a coefficient expressing the radiating quality of the surface.

If the radiating quality is equal for both hemispheres the central body will accordingly assume a temperature which is the arithmetical mean of those of the two hemispheres. When, however, the radiating surfaces are different, the temperature of the central body will incline towards that of the better radiator.

This law can be generalized. If different portions of the surrounding sphere are of different temperatures and of different radiating qualities, the ultimate temperature of the central body may be expressed by the formula

$$T = \frac{\Sigma t \,.\, a \,.\, c}{\Sigma a \,.\, c},$$

t being the temperatures, a the areas and c the coefficients of radiation

of the different portions of the spheres, and if the radiating condition of the whole surface is uniform, and besides if the entire surface is taken as a unit, the formula is reduced to $T = \Sigma t \,.\, a$.

Now suppose we remove a small portion of the surrounding sphere, say $\frac{1}{100}$, and substitute another piece, the temperature of which is 100° higher, the effect upon the central object will be to raise its temperature $\frac{1}{100}$ of $100° = 1°$, or in general, $T' = T + a\tau$. [1]

On this proposition I based my experiment, assuming the firmament to be the surrounding sphere, and the sun the heated portion thereof; but instead of using a globular central body, I used a flat piece of blackened sheet brass, under which I placed a thermometer, guarding the whole combination on the lower side as well as I could from loss of heat by conduction. I thereby gained two decided advantages. The whole receiving surface being exposed to the same conditions, no internal exchange of heat was occasioned after the terminal condition of heat was established, and further, the radiating surface being reduced to one-fourth, for the same bundle of solar rays received, the heating effect was increased, and the error of observation accordingly reduced.

The described instrument was exposed to the sun on the roof of a house, and after the thermometer came to a rest it indicated 50° C. Then the sun was screened off by a screen just sufficiently large to shade the whole instrument, and the thermometer came down to 28°. Several repetitions of the experiment yielded similar results, the difference always being about 22°.*

The diameter of the sun being about 0° 32′, the area covered by him is $\frac{1}{184000}$ of the entire firmament, but the effect of the sun having been quadrupled, due to the shape of the instrument, the proportion to be considered is $\frac{1}{46163}$.† The temperature of the sun is therefore $46162 \times 22 = 1{\cdot}015{\cdot}586°$, provided our premises are correct, and also provided the radiating quality of the sun is equal to that of the rest of the firmament. The ray-absorbing quality of any surface being equivalent to the radiating quality; and the universe being a perfect absorber of rays, and the atmosphere a poor reflector, the sphere surrounding our experiment can be regarded as a very good radiator, and

* In a subsequent discussion, upon the statement of Professor Snyder that this difference was found = 29° by other observers, I admitted that the result of my observation may have been impaired by moisture in the atmosphere, on the day of the experiment.

† Professor Snyder doubted the propriety of this conclusion in the subsequent discussion.

unless the sun's surface is an equally good radiator, the above estimate is too small. Moreover, the absorption of part of the solar rays by the atmosphere, will doubtless affect this result somewhat, but to avoid complications this factor will here be totally disregarded.*

This estimate ranges among the highest of the estimates mentioned at the beginning, and since the lower estimates cannot be entirely discountenanced, I endeavored to find where I might have drawn an erroneous conclusion. There is only one proposition to which an error might be attributed, namely the assumed law that the radiation is in direct proportion to the temperature. It might be suggested that the radiation increases as the square of the temperature. At the first glance this supposition seems to be unwarranted, as apparently conflicting with former observations, but a closer investigation will disperse this objection. Assuming for a unit of radiation, the heat radiated from a perfect radiator of 1° absolute temperature, the radiation from the same surface when heated to the freezing point of water would be 273^2, and when heated 1° higher $(273 + 1)^2$. The difference $= 547$ is an equivalent of the heat exchanged between two surfaces of those temperatures. The exchange of heat between two surfaces of 0° and 10° (273° and 283° absolute) is 5560, which is very little more than ten times the former result. We see, therefore, the radiation is still approximately in proportion to the difference of temperature. For higher temperatures, however, the radiation would increase considerably, for instance, the exchange of heat between surfaces of 99° and 100° respectively, would be $373^2 - 372^2 = 745$.

I thereupon searched in the library to find if former observations indicated such an increase, and in one text-book I found the statement that the radiation is approximately in proportion to the difference of temperature as long as this difference remains within certain limits, but that for greater differences the radiation increases more rapidly. Considering that most of the experiments were made with low temperatures and that the difference was increased by raising that of the radiating object, this statement seems to confirm my supposition.

There are, however, still other facts indicating that the radiation increases with a higher power of the temperature. The radiant heat

* It was not so much my object to arrive at a very close figure as to get a general insight. The following considerations will show that other questions will have to be answered first before we can even hope to arrive at a satisfactory result.

emanating from the sun is of a most complicated character, it being composed of innumerable series of rays of different order that can be dissolved by means of a prism, and can be projected upon a screen, where they form the spectrum, the luminous rays, of course, being regarded as heat rays capable of affecting the retina of the human eye. Heat, radiated from any object heated to incandescence, shows the same characteristic. When we watch the formation of the spectrum while the illuminating object is being heated, we first notice the appearance of the red rays, which then are very faint. As the heating is continued, the orange, then the yellow, the green, and finally, also, the blue and violet portion of the spectrum is developed, while at the same time the red portion is growing more intense. We may infer from this observation that the various orders of rays are due to various temperatures, and besides, that as the heating is continued, not only new series of rays are added, but the rays due to lower temperatures are intensified.

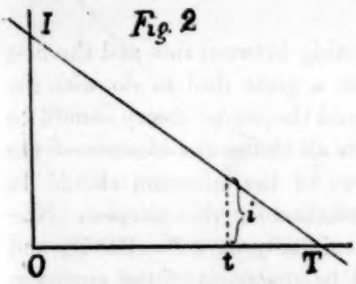

Fig. 2

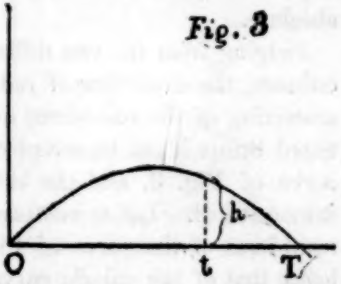

Fig. 3

There is no reason why this inference should not also be extended to the non-luminous rays, or rays due to lower temperatures, and hence, a compound ray emitted from an object of the temperature T can be represented by the triangle $O\ I\ T$ (Fig. 2) where the ordinate $O\ T$ measures the order, and the abscissa $O\ I$ the intensity of the component ray. In this diagram it is assumed that the intensity of any of the component rays due to the temperature t is $i = (T - t)\ .\ c$. The caloric value or heating quality of any of the component rays is equal to the product of the intensity into the appertaining temperature, and is therefore $h = t\ (T - t)\ .\ c$, which is the equation of a parabola. Consequently, if we lay out another diagram showing the caloric value of the different component rays, its form will be as shown in Fig. 3, and we are thus led to the conclusion that different portions of the spectrum ought to show different heating qualities. This supposition

is fully confirmed by former observations, for this diagram reminds us decidedly of the caloric curve representing the heat developed in different parts of the spectrum.

This is, I believe, the first attempt of explaining the caloric curve of the spectrum on a purely logical basis, and this interesting development considerably encouraged me to proceed.

The next thing was to determine the total caloric value of the compound ray, which is $H=\int_o^T t(T-t)c.dt=\frac{c}{6}T^3$ and according to this formula the radiation increases even as rapidly as the cube of the temperature. The formula [1] will accordingly be changed to $T^{'3}=T^3+\alpha\tau^3$ and by substituting the values found by the experiment we find $\tau=6670$, to which we have to add the initial temperature of the experiment (301° absolute), to obtain the solar temperature = 6971° absolute.

Judging from the vast difference existing between this and the first estimate, the exact law of radiation has a great deal to do with the answering of the considered question, and the above theory should be tested before it can be accepted. Before all things the identity of the curve of Fig. 3, and the caloric curve of the spectrum should be demonstrated. Let us compare their maxima for this purpose. The maximum of the curve of Fig. 3 is evidently at $\frac{1}{2}T=3485°$, and hence that of the caloric curve should be at a point of the spectrum corresponding to this temperature. But inasmuch as a heated object begins to emit red rays at about 900° abs. we may conclude that the ultra red rays in which the maximum of the caloric curve is located, are due to even less than 900°. The difference of these two figures does not speak very favorably for the foregoing speculation. It is true, the prism disperses the rays in an unequal proportion, spreading the rays of higher order more than those of lower orders. This would distort the caloric curve, and shift its maximum into the ultra red portion, while it may be located in the red rays; but this can hardly account for the above difference.

It will be remembered that in the foregoing calculation I assumed that the intensity of the individual rays was increasing in the same proportion as the temperature rises, and suspecting an error in this assumption, I tried other relations. By assuming $i=(T-t)^2c$ I

obtained the curve of intensity as shown in Fig. 4, and that of caloric energy, as shown in Fig. 5. The formula, [1,] changes to $T'^4 = T^4 + ar^4$, and by substituting the values found by the experiment r will be found $= 3335$, and the solar temperature $= 3635$, and the maximum of the curve of Fig. 5 $= \frac{T}{3} = 1212°$. Now it will be seen that Fig. 5 bears more resemblance to the caloric curve than Fig. 3, and the difference of its maximum and the figure supposed to represent the maximum of the caloric curve may be accounted for by distortion; at any rate these results are more satisfactory than those of my former calculation. It may however be, that the law of radiation is more complicated, and these theories are yet in the form of crude suggestions.

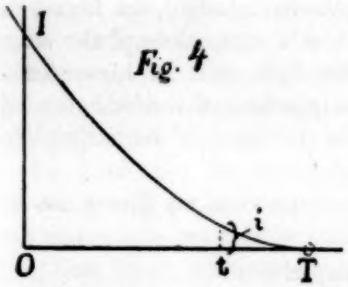

Fig. 4

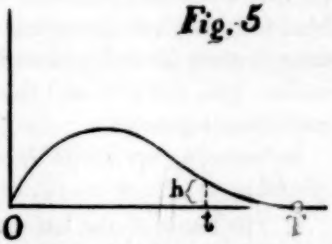

Fig. 5

My endeavors were next directed to finding additional means for corroborating the supposition that the radiation increases at a higher rate than the temperature.

Turning our attention to our first ideal experiment, it is evident that the object inclosed by two hemispheres of different temperatures should not assume a temperature equal to the arithmetical mean, as first supposed, but should rise to a higher point. If one of these hemispheres is at the freezing point, and the other at the boiling point of water, the calculated temperatures are 53·8°, 57·6°, and 61·1°, respectively, as we assume the radiation to be increasing as the square, cube, or the fourth power of the temperature.

I made preparations for a practical test, but not having at my command the means for producing a vacuum, I had to content myself without. I was well aware, though, that owing to the presence of air an exchange of heat by convection was inevitable, and the result of the experiment was accordingly impaired. However, as it can be safely assumed that the effect of convection tends to maintain the

arithmetical mean, a rising of the temperature of the inclosed object above this mean would indicate the tendency of the radiation. The experiment answered the question affirmatively, the thermometer rising to nearly 54°. Had the air been excluded the thermometer would presumably have risen to a higher point. Indeed, a series of such experiments made with different temperatures, in a vacuum, might disclose the exact law, however complicated that law may be.

In reviewing the preceeding, it appears rather curious that the estimates based on one single experiment range nearly from the highest to the lowest of the estimates alluded to at the beginning. Of all these figures the last one seems to be the most reasonable, for there exists a striking similarity between the solar light and that of the oxy-hydrogen flame or the electric light, and the temperatures of these latter lights are usually estimated at 3000° or thereabouts. Indeed, the lowest of the first mentioned estimates were based on a comparison of the solar heat with the heat emanating from a lime light, and the higher estimates having probably been based on a misconception of the law of radiant heat, the proposed theory may be the means of reconciling the conflicting estimates.

In summing up it will be seen that in support of my theory can be offered:

1. The result of the last mentioned experiment.
2. The ready explanation of the caloric curve of the spectrum.
3. The prospect of bringing to unison the conflicting estimates of the solar temperature.

My attention was not only directed to the temperature of the sun, but also to its relation to that of our earth, and I shall select the last law and estimate as a basis for the figures used to exemplify the conclusions bearing on this subject.

If the globe of a thermometer was suspended in space at a distance from the sun equal to that of our earth, its temperature would become $t = \sqrt[4]{\frac{T^4}{184650}} = 175°$ abs. $= -98°$; the heat it would receive from the more distant stars being disregarded. In exposing a flat plate of non-conducting material at right angles to the sun, the side facing the sun would attain a temperature $t = \sqrt[4]{\frac{T^4}{46162}} = 228$ abs. $= -25°$.

The surface of the moon is exposed to similar conditions and will

accordingly, during the long lunar day, be heated to a point never exceeding —25°, while the average temperature of the moon would be —98°. But how does this speculation agree with the temperature of our earth? Indeed, the old question as to the cause of the cold on high mountains is now reversed. We have to inquire why it is so warm there, and why it is still warmer in the lower regions. The interior heat of the earth cannot account for this great difference. An answer to this question is, however, not very remote. In exposing a thermometer to the clear nocturnal sky, we find that notwithstanding the greatest care in guarding it from receiving heat by any ways other than radiation, the temperature of the air has a decided influence upon that indicated by the thermometer. The air must therefore be capable of radiating heat and cannot be transparent for rays of the same character, although it is transparent, almost to perfection, for rays of higher order, for luminous rays. Only a portion of the solar rays penetrate the atmosphere and strike the earth, which partly reflects, partly absorbs them and return the heat appropriated by absorption in form of rays of lower order.

To these rays the atmosphere is opaque; they are accordingly absorbed, and retained near the surface of the earth. The action of the atmosphere can thus be compared with the action of valves, admitting heat freely, but preventing its escape.

The effect would be a continual increase of heat near the surface of the earth, which, however, is balanced by convection of heat to the outskirts of the atmosphere, from whence it is radiated and lost into the universe. But convection being comparatively slow, a surplus of heat will prevail in the lower regions.

I concluded that if this theory be correct, a piece of blackened metal exposed to the sun, would ultimately be heated to a higher degree when covered by a flat piece of glass than when uncovered; for the glass would act in the same manner as the atmosphere. In order to test this, it was my intention to procure a suitable piece of glass from an optician, but upon stating the purpose for which I wished to use it, I was informed that the fact was observed before, and then I thought it unnecessary to repeat the experiment.

In a recently invented solar boiler (Mouchot's), advantage is taken of this fact. The boiler upon which the solar rays are concentrated by a reflector, is enveloped by a glass bell. The rays of higher order of

the sun are readily transmitted, but those of lower order returned by the boiler, are arrested and thus retained inside of the bell.

Returning to the subject, it appears now that the thickness and condition of the atmosphere govern in a great measure the temperature of the earth, and a number of inferences can be based on that theory.

Carbonic acid being a better absorber of heat, by many times, than either oxygen or nitrogen, the small percentage of this gas in the atmosphere may have a great deal to do with our temperature. At a past period the percentage of this gas may have been less than at present. This might explain the glacial period. Before the immense fields of coal were deposited under ground, the air must have been richer in carbonic acid, and hence a better protector of heat. This may account for the luxury and abundance of vegetable growth of that period.

Thus my studies were carried farther than I originally intended, but it is almost impossible to investigate any subject without being led on other topics. The laws of nature are so closely related to each other, that no line of division can be drawn, and one discovery suggests another.

A STANDARD GAUGE SYSTEM.*

By GEORGE M. BOND, Hartford, Conn.

In a paper presented at the May meeting of the Society last year, a statement, or "report of progress" was submitted, showing the method adopted by the Pratt & Whitney Company, of Hartford, Conn., by which the question of practically establishing a standard for size gauges was to be scientifically determined, accurately subdividing the Imperial yard into feet and inches and fractional parts of an inch, and describing briefly the extent to which was carried the scientific research found absolutely necessary for such an undertaking; it remains now to present to the consideration of those who may be interested, a statement of the results proceeding from the practical application of all the thorough, conscientious investigation of Professor Rogers, of Harvard College Observatory, whose invaluable experience and professional services, in obtaining for the company the transfer and subsequent subdivision of the British yard, gave the foundation for

*From advance sheets of the transactions of the American Society of Mechanical Engineers.

what has been accomplished, enabling the company to feel warranted in earnestly inviting an inspection of the means now available for the production of standard sizes, and asking for it the endorsement of the engineering profession, should it be found worthy of such necessary support.

The comparator referred to in the previous paper, has been placed in position upon brick piers in a room outside the main building, erected especially for it, and is comparatively free from the jar and tremor of the machinery, even unaffected by the jar of passing trains (the tracks of the New York, New Haven and Hartford, and of the New York and New England Railroads being quite near), the rigidity of the instrument and the excellent workmanship in its construction preventing any perceptible vibration during an observation, even when the high power microscopes, magnifying 150 diameters, are used.

The illumination required in using these microscopes is perfectly attained by reflection, using a plate-glass mirror placed outside of the window of the comparing room, at an inclination of 45 degrees, giving clear diffused light, cloudy weather even improving the general effect, as the light is then whiter than that reflected from a clear blue sky, and the lines on the standard bar, as seen through the medium of the Tolles' illuminating prisms with which the objectives are fitted, are clearly and sharply defined at any time during daylight, and in any position of the microscope plate; by thus avoiding the use of artificial light and consequent effect of a variable temperature, far more satisfactory results are obtained.

The investigation for the determination of the necessary corrections for errors due to horizontal or vertical curvature of the path of the microscope plate, has shown conclusively the unexcelled workmanship in the construction of the comparator; as an instance of how slight these errors really are, it was found after repeated observations, the means being carefully collected, that the horizontal curvature, *i. e.*, the bending sidewise of the cylindrical guides or ways upon which the microscope plate slides, at the part investigated, was that having a radius of *eleven miles*, and a consequent correction to be applied of about one ten-thousandth of an inch in 18 inches, the latter distance referring to the position of the measured standard when placed either side of the line of motion of the centre of the microscope plate, moving between fixed stops, and which is the constant quantity to which is referred the subdivisions of the standard bar; as the microscope is usually within

one inch, rarely over two and a half, from the centre line of the stops or caliper jaws between which the end measure pieces or the cylindrical gauges are placed, this correction evidently becomes too small to be applied practically, within the limit of a six-inch gauge; for a foot or a yard it would become necessary, as the variation of the chords of the subtended arcs then becomes quite perceptible. The errors due to inequality of temperature in the standard steel bar and the hardened steel end-measure gauges must be carefully guarded against, the latter effect being far more important, practically, and often very misleading. In the case of a four-inch hardened steel end-measure gauge experimented upon, the coefficient of expansion being nearly one one-hundred thousandth of its length, one degree of change of temperature from that maintained in the reference bar, introduces an error of nearly one twenty-five thousandth of an inch in the total length, and hence, as a change or inequality of five or even ten degrees might be easily overlooked, the four-inch gauge would be found to be from one-five thousandth ($\frac{1}{5000}$) to one twenty-five hundredth ($\frac{1}{2500}$) of an inch too short, when equality of temperature is restored; when it is asserted that an actual variation of so minute a quantity as *one thirty-thousandth* of an inch, and even less, can be readily detected by any tool-maker familiar with the use of an ordinary micrometer or a close gauge, the importance of keeping *within* this limit is apparent,—of course, this shortening effect is not so marked in smaller sizes, still the ratio is the same, and this error must be carefully avoided.

The subdivisions upon the six-inch hardened steel standard bar have been carefully investigated upon the new comparator, to determine how nearly these inch spaces equal each other, the total length of the four inches which are ruled upon this six-inch bar being *exactly standard* at 62 degrees Fahrenheit, according to the official report of Professor Rogers, received December 1st, 1881, and in this report, the results obtained by him, determining this relation of the inch spaces to each other, was found to agree closely with the results obtained by me, as the following comparison will show, these minute corrections being necessary in accurately determining the subdivisions of the Imperial yard, which they represent:

Corrections.	Prof. Roger's Report.	Results obtained.	
Total 1 inch, *add*,	0.000008	0.000008	($\frac{1}{3}\frac{1}{6}$ yard.)
Total 2 inches, *subtract*,	0.000026	0.000027	($\frac{1}{1}\frac{1}{3}$ ")
Total 3 inches, *subtract*,	0.000005	0.000006	($\frac{1}{1}\frac{1}{7}$ ")
Total 4 inches,	correct	correct	($\frac{1}{0}$ ")

The results given in the last column are the *means* of a number of observations, taken at different times and under various conditions of temperature, etc., and cover a period of about four weeks, the final results having been obtained December 31st.

The value of the divisions of the micrometer employed was carefully determined in order to reduce them to the same unit used by Professor Rogers, and was found, using the microscope marked "B," to equal $\frac{1}{58500}$ of an inch (0.000016, nearly).

When it is considered that the two results were obtained under different conditions, and using different microscopes, and with comparators differing in construction, the correctness of the *principle* upon which the comparison is founded, certainly needs no other proof.

The method of obtaining this relation of the separate inches upon the six-inch standard, was referred to in the former paper, and is that of comparing each inch with a constant distance moved over by the microscope plate between fixed stops, a constant pressure of contact being obtained by the use of electro-magnets, the separate inch spaces being thus referred to an *invariable* quantity or distance, and their relation to each other consequently determined.

To explain more fully this operation, the method adopted is as follows: A series of readings is taken at the zero or initial line of the first inch space, using the micrometer referred to, the microscope plate being held firmly against the fixed stop by the electro-magnet; the microscope then moves with the sliding plate until the latter is in contact with the other fixed stop, and held by the electro-magnet, the plate having moved as nearly an inch as it may conveniently be done,—generally a little more than an inch, in order to have the *sign* of the reading always the same,—from three to five readings of the micrometer are then taken at each position of the microscope, and the order reversed, to eliminate possible error; the first inch is thus compared with a fixed quantity, and the same operation repeated for the remaining inch spaces.

The difference between the distance moved by the microscope plate and the distance between the defining lines representing inches, is found by subtracting the *means* of the readings obtained, and thus eliminating the possible error of any single observation.

The following is a series of micrometer readings, and comprises the means of all the observations by which the corrections of the separate inches were obtained, illustrating the system adopted, and which has

been used invariably by Professor Rogers in his investigations of the subdivisions of the yard and meter bars, now in the possession of the Pratt and Whitney Company.

COMPARISON OF INCHES.

	L.	R.	L.	R.	
	58.1	65.8	58.0	65.5	Reverse order.
1st inch	58.6	66.0	58.1	65.8	
	58.5	65.4	58.0	65.8	
Mean	58.4	65.7	58.0	65.7	
	58.0	65.7			
Mean	58.2	65.7			

R − L = + 7.5 divisions of micrometer.

	L.	R.	L.	R.	
	56.2	65.8	55.4	65.4	Reverse order.
2d inch	55.6	65.8	56.0	65.4	
	56.2	66.0	55.4	66.0	
Mean	56.0	65.8	55.6	65.6	
	55.6	65.6			
Mean	55.8	65.7			

R − L = + 9.9.

	L.	R.	L.	R.
	55.0	63.0	57.0	63.0
3d inch	55.8	63.0	57.0	63.5
	55.7	63.6	57.0	62.8
Mean	55.5	63.2	57.0	63.1
	57.0	63.1		
Mean	56.3	63.1		

R − L = + 6.8

	L.	R.	L.	R.
	57.4	64.3	56.0	64.2
4th inch	57.8	64.8	56.1	64.5
	57.8	64.8	56.8	64.5
Mean	57.6	64.6	56.3	64.4
	56.3	64.4		
Mean	56.9	64.5		

L − L = + 7.6

CORRECTION Σ

+ 7.5 + 0.45 + 0.45 = correction for first inch.
+ 9.9 − 1.95 − 1.50 = correction for total 2 inches.
+ 6.8 + 1.15 − 0.35 = correction for total 3 inches.
+ 7.6 + 0.35 ± 0.00 = correction for total 4 inches.

Mean + 7.95

The differences of the observed inch spaces with respect to the constant quantity obtained by the motion of the microscope plate, are added and their mean taken, from which the corrections are determined with the proper signs; in order to check the accuracy of the latter work, these corrections are added, the final result being evidently zero, the column under "Σ" showing this algebraic sum.

It may be appropriate here to state that the six-inch bar upon which these four-inch spaces are traced, is a standard which is, without doubt, the only hardened steel *line-measure* bar in existence, which is exactly one-ninth part of the Imperial yard at 62° Fahrenheit, and Professor Rogers considers it as such in his report, before referred to.

In order to apply these subdivisions, which include all sizes, from one-sixteenth of an inch to four inches, varying by sixteenths, to a practical form, fixtures have been provided and are in constant use, for reducing to *end* measure the distances thus accurately spaced, and a caliper attachment has lately been added from plans proposed by Professor Rogers, by which the diameter of existing cylindrical gauges, as well as the length of end-measure pieces from one-sixteenth of an inch to six inches may be tested with the same precision that characterizes the investigation of the linear spacing of the standard bar, also providing means for a rigid inspection of finished gauges before they leave the works, thereby insuring uniformity.

To illustrate how nearly alike two pieces may be made, two standard inch end-measure gauges were worked down under the microscope, independently of each other, using the lines upon the ruled standard reference bar and the fixture referred to, which, when compared with each other by the most careful tests, using close or "snap" gauges, and tested thus by tool-makers experienced in work requiring the utmost practical precision, neither piece could be singled out as the larger, the effect of unequal expansion caused by temperature being avoided during the test. Under the microscope, both pieces were found to be exactly alike by a *single* observation, while the comparison, by a series of readings showed a mean difference between the two pieces of one-tenth of a division of the micrometer, and when it is remembered that one division has a value of only $\frac{1}{88000}$th of an inch, the duplication, it may be assured, is certainly satisfactory, and is clearly within a practical, if not a theoretical limit of accuracy.

Having thus the means for closely reproducing established sizes, and no possible wear occurring to the bar from which these sizes are taken, the accurate duplication becomes a comparatively simple operation.

In order to produce standard work within the limit of a yard, or a meter, there has been furnished by Professor Rogers, two steel yard and meter bars, referred to in the previous paper, one of these bars tempered, the other being left soft, but having hardened steel plugs, which are adjustable, for the purpose of bringing the surfaces into focus under the microscope; upon these hardened plugs the lines are ruled, both bars having line and end-measure, thus providing means for testing the accuracy of the pitch of screw threads of any desired length, and for standard length gauges up to thirty-six inches, or to a meter.

The coefficient of expansion has been determined for each by Professor Rogers with the most scrupulous exactness as stated in his report, and also the relation, at 62°F., between these steel bars and the two bronze standards, both of which are line measure, (the latter are described in the paper previously referred to) so that gauges of any size may be made almost independently of temperature, other than the care required in keeping this condition as nearly uniform as possible for both the reference and the measured bar during the time of the transfer, or the determination after having been transferred.

The subject of accurately producing standard leading screws is receiving its share of attention, and those who use micrometers will readily understand its bearing upon the precision with which they may be made, and how unsatisfactory because of the necessary corrections to be applied in many instances, even when standard at some one part of the divided head—a uniform lead or pitch of the screw, however much may be the total error (within a reasonable limit), making a great improvement in their construction.

Besides a complete set of end-measure gauges, varying by sixteenths from one-quarter to four inches, there is now ready for inspection a complete plant, consisting of tools and fixtures for producing the standard United States or Franklin Institute thread gauges, every detail having been carefully considered, and every difficulty overcome in the operation for perfecting, not only these standard gauges as to size, but the pitch of the thread, the correct angle, and the width of flat at the top and bottom of the thread. The accuracy of this work is now open to the inspection of all who may be interested, and rapid duplication by *machined* work is now an assured success.

It is the conviction that the "bottom" has finally been reached, that warrants the Pratt and Whitney Company in thus inviting a

thorough inspection of the means available, and the methods employed, for producing standard gauges, and earnestly desiring an impartial verdict as to its accuracy and practicability, whether or not, the system as adopted and carried out, has any real merit upon which the confidence of those using gauges for interchangeable work may be safely based.

DISCUSSION.

PROFESSOR ROBINSON: This paper is of the highest merit and of the greatest possible interest to members of the Society, and it is a matter of great satisfaction to the mechanical engineers of this country that there is some one who is able to take hold of this question and treat it so ably as it has been treated; and inasmuch as the methods and results, as stated by the reader, are laid open for inspection by others, I think it is due, in consideration of the amount of effort and expense which has been given to this matter, that the Society, as a matter of duty, should appoint a committee to avail itself of the privileges offered of investigating this, and of making such a statement regarding it as will be found advisable; and undoubtedly this is a thing which the Society will be willing and anxious to endorse in every particular as a standard of the country. For one, I should be glad to see a committee appointed to give this matter the attention it deserves.

PROFESSOR EGLESTON: I notice that there is no reference in this paper to any instrument in the shape of a caliper of any kind used as a gauge. I do not know whether the members of the Society are familiar with the fact that in 1875 the Institute of Mining Engineers appointed a committee on standard gauge, and that committee came to just exactly the conclusion which is expressed here, that diameters or linear measures ranging in fractions of a millimeter or an inch were the only gauges which were standard or could be standard. It is a peculiar gratification, as a large part of the work fell to my hands, to see that idea so fully sustained. It is a matter of a great deal more importance than perhaps would appear just now. I believe the English engineers are again agitating the question of standards, and are going back to the old caliper idea. So I have heard recently. So I think it is really a retrograde movement. Most of you may know the fact, but we discovered in the course of our investigations

that if you take a dozen standard gauges, so-called, out of any package, you will find no two of them alike.

THE PRESIDENT: I suppose the members would be interested if Mr. Pratt would tell us how they went to work in this undertaking. Mr. Pratt told us the story at Hartford, but many gentlemen are here to-day who were not with us then, and I presume it would be very interesting to all to know how Messrs. Pratt and Whitney were led into this prolonged, expensive, and nice investigation.

MR. PRATT: I will relate the story in the briefest possible way. We were called upon to furnish a set of standard thread gauges, and of course the first thing to do was to get the sizes, and upon examining the different makes of gauges we found no two sets alike, and we were forced to commence, as we thought, at the bottom, and at that time, in sending about a foot-piece that we had obtained, we found that those investigating it did not agree upon its value. Among others Professor Rogers was applied to, to investigate the foot-piece, and he had quite a struggle over it with some of our prominent manufacturers of gauges. They could not agree, and Professor Rogers took it upon himself, at his own expense, to go to Europe, and go to the bottom of the thing. He visited the best authorities in Europe, and spent four months there in investigation. After we had obtained the services of one of the graduates of the Stevens Institute, and in connection with Professor Rogers, we constructed two comparators, one of which Professor Rogers has himself, and one of which we have; they being exactly alike. After Professor Rogers returned he investigated the foot-piece, and found it to be about what he had found it to be before, and then, after the new comparator was finished, he found his statement verified. Previous to this time, fortunately, Professor Rogers had been for several years constructing a ruling machine, and he had it completed about this time. We have gone very carefully into this thing. I do not feel egotistic about it at all. What we want is that every one who is interested in the matter, every society that takes any interest in it, should come and examine our methods and our measurements. If they are good, let us have a standard. If they are not, let us throw them away. It has cost us probably twenty thousand dollars to-day, and I am willing to throw it away if anybody can show us better. We want a standard, and I will not stand in the way of any one else

who has a better machine. I feel very much interested in the subject, myself; and I think we shall succeed in what we have undertaken.

Supply of Air to Houses.—MM. Autier and Mongey have devised plans for the distribution of cool, fresh air to houses. The former proposed to employ a feeble pressure, while the latter recommends a pressure of five or six atmospheres, together with special refrigeration, in order to obtain increased cold by expansion, on the plan of the frigorific engines of Windhauser, P. Gifferd, etc. The Holley system, as employed by the Steam Supply Company in Lockport, is quoted as an evidence of the economy of large public provisions for the distribution of such means of family comfort as heat, gas, fresh air, and relief from the oppressive heats of summer. The distribution of such air would not only contribute to bodily comfort and public health, but it would also retard the fermentations and decompositions of animal and vegetable substances, and it might, at the same time, be employed to furnish motive power.—*Chron. Industr.* C.

AN EXTENSION OF THE THEOREM OF THE VIRIAL AND ITS APPLICATION TO THE KINETIC THEORY OF GASES.*

By H. T. Eddy, C. E., Ph. D., University of Cincinnati.

1. Introductory.

Clausius published, in 1870, a paper upon a *New Mechanical Theorem Applicable to Heat*,† which he designated as the *Theorem of the Virial*, and which he applied to the stationary *progressive* motion of the molecules of gases.

The object of this paper is to demonstrate an analogous theorem applicable to the stationary *rotary* motion of the molecules of gases, and by the aid of these two theorems to improve, to some extent, the kinetic theory of gases, especially in removing an heretofore inexplic-

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* From the Scientific Proceedings of the Ohio Mechanics' Institute, for March, 1883.

† Berichte der niederrhein. Gesellsch. für Natur u. Heilkunde, Juni, 1883.
Phil. Mag., Series 4, vol. 40, 1870, p. 122.
Pogg. Ann., vol. 141, p. 124.

able contradiction between the theoretic and experimental values of the ratio of the specific heats of a gas. To accomplish this most simply, it has seemed best to repeat here, in the first place, the more important parts of Clausius' original investigation, which he has supplemented by a number of important papers which have been translated and published in the *Philosophical Magazine*, between 1870 and 1876. Of these papers, the one most closely related to the original paper is one "*On Different Forms of the Virial.*"*

2. Clausius' Theorem respecting Stationary Progressive Motion.

A material system is said to be in stationary motion when the bodies of which it is composed do not continually depart from their initial positions, and their velocities do not continually recede from their initial values. The molecules of a gas in equilibrium are regarded as constituting such a system. For the sake of definiteness, let the system of molecules under consideration be that constituting one unit of mass of gas contained within impervious walls, although the same laws will evidently hold in case the walls are merely imaginary boundaries conceived as separating the unit of gas from other surrounding units. Let m be the mass of any molecule of this gas, and $x\,y\,z$ its rectangular co-ordinates referred to any origin; let $X\,Y\,Z$ be the components along the axes of xyz respectively of the resultant of all the external forces acting upon the molecule m, taken as positive, when they tend to increase the co-ordinates $x\,y\,z$ respectively.

Now, by the principles of the differential calculus, we have the identical equation,

$$\tfrac{1}{2}\frac{d^2(x^2)}{dt^2} = \frac{d}{dt}\left(x\frac{dx}{dt}\right) = \left(\frac{dx}{dt}\right)^2 + x\frac{d^2x}{dt^2}, \qquad (1)$$

as may be seen by performing the differentations expressed in the first two terms.

But by the fundamental equations of dynamics expressing D'Alembert's principle:

$$m\frac{d^2x}{dt^2} = X. \qquad (2)$$

Substitute from (2) in (1), etc.

$$\therefore\ \frac{m}{2}\left(\frac{dx}{dt}\right)^2 = \frac{m}{4}\frac{d^2(x^2)}{dt^2} - \frac{x}{2}X. \qquad (3)$$

* Phil. Mag., Series 4, vol. 48, 1874, p. 1.

The first member of (3), being one-half the product of the mass by the square of the velocity along x, expresses the energy of progressive motion of m parallel to x at any instant when its co-ordinate is x, and the force moving it in that direction is X.

In order to find the mean or average value of this energy during any interval of time t, (3) must be multiplied by dt, integrated between the limits 0 and t, and then the result divided by t, this being the ordinary process for finding the mean value of any function for the time t.

$$\therefore \frac{m}{2t}\int_o^t \left(\frac{dx}{dt}\right)^2 dt = \left\{\left(\frac{d(x^2)}{dt}\right)_t - \left(\frac{d(x^2)}{dt}\right)_o\right\} - \frac{1}{2t}\int_o^t x\,X\,dt. \quad (4)$$

The two integrals in (4) are, as just stated, expressions for the mean values of the corresponding expressions in (3): but the quantity not under the integral sign is of a different nature; it is the difference between the final and initial values (as expressed by the subscripts) of a function whose final and initial values may (if t be properly chosen) be equal, in which case the difference would vanish. But it is unnecessary so to choose t that the difference vanishes; for, by reason of the divisor t, it appears that if t be taken sufficiently large, the term under consideration vanishes, even though the final and initial values are not equal, since they cannot recede indefinitely from each other. That they cannot so recede appears from the identical equation, obtained in the same manner as (1):

$$\frac{d(x^2)}{dt} = 2x\frac{dx}{dt}, \quad (5)$$

from which it appears that the expression under consideration is dependent upon the products of quantities (co-ordinates and velocities) which, by the definition of stationary motion, cannot recede indefinitely from their initial values.

Let now $x\,y\,z$ denote no longer the co-ordinates of m at any particular instant, but, instead, their mean values during the time t; and, similarly, let $X\,Y\,Z$ denote mean values, and let $x'y'z'$ be the corresponding mean velocities along the axes. Hence, we may write (4), and the two similar equations with respect to the axes of y and z, as follows:

$$mx'^2 = -\,x\,X, \quad my'^2 = -\,y\,Y, \quad mz'^2 = -\,zZ, \quad (6)$$

in which, as just stated, the variables express mean values during the interval t, which may be taken so large as to give them sensibly constant values.

Let the unit of gas under consideration consist of n molecules, which

may have equal or unequal masses; then equations like (6) apply to each of the n molecules, whose masses may be distinguished one from another by giving to m successive subscripts from 1 to n. Suppose these equations formed, and take their sum:

$$\therefore \tfrac{1}{2}\Sigma_1^n m(x'^2+y'^2+z'^2) = -\tfrac{1}{2}\Sigma_1^n(xX+yY+zZ). \qquad (7)$$

The first member of (7) is the kinetic energy of the progressive motion of the members of the systems, and the last member is called the *virial* of the system, and depends for its value upon the mean forces acting upon the molecules and upon their mean positions.

The theorem which has now been demonstrated, may be thus stated: the mean kinetic energy of the progressive motion of a system in stationary motion is equal to its virial.

The forces which act upon the molecules of the gas will, in general, consist of two parts: the external forces, which may be taken to be the pressure at the surface of the walls of the enclosing vessel, and the internal forces, due to intermolecular attractions or repulsions. To compute the virial of the external pressure, let the closed surface containing the unit of gas under consideration be of any shape whatever. It is evident that the pressure exerted upon the enclosed gas in equilibrium will be normal to the surface. Let p be the pressure per unit of area, and let dS be the element of area of the enclosing surface, and l the cosine of the angle which the normal to the element makes with the axis of x. Also let $X = X' + X''$, in which X' is the part of the total component force X, which is due to the pressure p, and X'' is the remainder of the component X, due to internal attractions, etc. It is to be noticed that the sign of p is opposite to that of X', because p tends to cause the molecules to approach each other, while X' tends, when positive, to make them recede from the origin, and so from each other. Then $l\,dS = dy\,dz$.

$$\therefore \quad -\tfrac{1}{2}\Sigma_1^n xX' = \tfrac{1}{2}\int xp\,l\,dS = \frac{p}{2}\int\int x\,dy\,dz. \qquad (8)$$

In (8) the single integration in the second member is to be extended only over the enclosing surface, for those molecules alone are acted upon by the pressure which are at the surface; but the double integration in the last member is to be extended throughout the whole volume v enclosed within the surface. In fact, the double integral in (8) expresses the total enclosed volume v occupied by the unit of gas:

$$\therefore \quad \text{by (8)}, \ -\tfrac{1}{2}\Sigma_1^n xX' = \tfrac{1}{2}pv, \qquad (9)$$

with similar equations for y and z, which, being added to (9), give the total virial due to the external pressure to be

$$-\tfrac{1}{2}\Sigma_1^n(xX'+yY'+zZ')=\tfrac{3}{2}pv. \qquad (10)$$

In order to compute the part of the virial due to intermolecular forces, let R be the attractive force between any pair of molecules, as m_1 and m_2, and let r be the distance between them; then is $(x_1-x_2)\div r$ the cosine of the angle which the attraction with which m_1 is drawn towards m_2 makes with the axis of x;

$$i.e., \quad -X_1''=\frac{x_1-x_2}{r}R, \text{ etc.}$$

$$\therefore\ -(x_1X_1''+x_2X_2'')=x_1\frac{x_1-x_2}{r}R+x_2\frac{x_2-x_1}{r}R,$$

$$\therefore\ -(x_1X_1''+x_2X_2'')=\frac{(x_2-x_1)^2}{r}R, \qquad (11)$$

with two similar equations with respect to the axes of y and z.

Now take the sum of the three equations similar to (11) for each different pair of molecules in the system between which intermolecular forces exist, and noticing that

$$(x_2-x_1)^2+(y_2-y_1)^2+(z_2-z_1)^2=r^2, \text{ etc.}$$

the virial of the intermocular forces becomes

$$-\tfrac{1}{2}\Sigma_1^n(xX''+yY''+zZ'')=\tfrac{1}{2}\Sigma rR. \qquad (12)$$

The sum of the right-hand members of (10) and (12) is the total virial of the external pressures and intermolecular forces. Should there be other forces of sufficient magnitude to be of importance, as gravitation, electrical forces, etc., they must be also computed and added to this sum. Neglecting all these, we obtain from (7), (10) and (12),

$$\tfrac{1}{2}\Sigma_1^n m(x'^2+y'^2+z'^2)=\tfrac{3}{2}pv+\tfrac{1}{2}\Sigma rR. \qquad (13)$$

3. A New Theorem Respecting Stationary Rotary Motion.

Let $A\,B\,C$ be the moments of inertia of any molecule of mass m, with respect to its principal axes.

Let $\frac{d\theta}{dt}, \frac{d\varphi}{dt}, \frac{d\psi}{dt}$ be the angular velocities about these principal axes, then are θ, φ, ψ angular co-ordinates with reference to some initial lines yet to be assumed.

Let LMN be the respective components about these same axes of the resultant of all the couples acting upon the molecule.

Then, by Euler's equation of rotary motion,

$$A\frac{d^2\theta}{dt^2} = (B-C)\frac{d\varphi}{dt}\frac{d\psi}{dt} + L, \tag{14}$$

with a similar equation with respect to each of the two remaining principal axes.

The following identity also holds:

$$\tfrac{1}{2}\frac{d^2(\theta^2)}{dt^2} = \frac{d}{dt}\left(\theta\frac{d\theta}{dt}\right) = \left(\frac{d\theta}{dt}\right)^2 + \theta\frac{d^2\theta}{dt^2}, \tag{15}$$

as appears by performing the differentiations expressed in the first two members.

Substitute from (15) in (14), etc.:

$$\therefore\ \tfrac{1}{2}A\left(\frac{d\theta}{dt}\right)^2 = \tfrac{1}{4}\frac{d^2(\theta^2)}{dt^2} - \tfrac{1}{2}(B-C)\,\theta\frac{d\varphi}{dt}\frac{d\psi}{dt} - \tfrac{1}{2}\theta L, \tag{16}$$

which, with a similar equation with respect to each of the two other principal axes, is an equation of rotation applicable to any solid body, in which the first member expresses the energy of rotation about the axis considered.

In order to apply (16) to stationary rotary motion, the mean value of its various terms must be found during the interval t, as was done previously in case of stationary progressive motion.

Let

$$\frac{1}{t}\int_o^t \left(\frac{d\theta}{dt}\right)^2 dt = \theta'^2,$$

then θ'^2 is the mean square of the angular velocity about the first principal axis.

The integral of the second term is

$$\frac{1}{2t}\left(\frac{d(\theta^2)}{dt}\right)_t - \frac{1}{2t}\left(\frac{d(\theta^2)}{dt}\right)_o$$

in which the subscripts denote the limits to be substituted. This expression vanishes ultimately, as appears from considerations like those adduced in connection with (4) and (5).

The mean value of the product $\frac{d\varphi}{dt}\frac{d\varphi}{dt}$, also vanishes, for it is evident that positive and negative angular velocities are equally frequent.

Let θ and L no longer denote particular values, but instead let them denote mean values of those quantities, and we have

$$A\,\theta'^2 = -\theta L, \quad B\,\varphi'^2 = -\varphi M, \quad C\psi'^2 = -\psi N, \tag{17}$$

Add these equations, and the sum for n molecules is

$$\therefore \tfrac{1}{2}\Sigma_1^n(A\theta'^2 + B\varphi'^2 + C\psi'^2) = -\tfrac{1}{2}\Sigma_1^n(\theta L + \varphi M + \psi N), \quad (18)$$

in which the first member is the total rotary energy of the system and the second member can be reduced to a form like that which has been previously obtained for the virial in case of progressive motion. For let

$$L = \rho_1 X', \quad M = \rho_2 Y', \quad N = \rho_3 Z', \quad (19)$$

in which X', Y', Z' are the mean component forces acting upon the molecules, with the exception of the intermolecular attractions, and ρ_1, ρ_2, ρ_3 are the arms of the mean couples L, M, N, respectively.

Let

$$x = \theta\rho_1, \quad y = \varphi\rho_2, \quad z = \psi\rho_3, \quad (20)$$

in which x, y, z are mean co-ordinates; then (20) will determine the initial lines from which θ, φ, ψ are measured.

By (19) and (20) we have

$$\Sigma_1^n(\theta L + \varphi M + \psi N) = \Sigma_1^n(xX' + yY' + zZ'), \quad (21)$$

$\therefore$ by (18),

$$\tfrac{1}{2}\Sigma_1^n(A\theta'^2 + B\varphi'^2 + C\psi'^2) = -\tfrac{1}{2}\Sigma_1^n(xX' + yY' + zZ'). \quad (22)$$

It is evident that the distribution of the kinetic energy of the system of molecules, both rotary and progressive, is effected by the encounters of the molecules with each other, and with the bounding surface. The progressive motion is also directly affected by the intermolecular attractions, while the rotations cannot be directly accelerated by these attractions, and this is the reason why they are not included in the forces entering the virial of rotation. When the inter-atomic attractions vanish, $X = X'$, $Y = Y'$, $Z = Z'$, and in all permanent gases these equations are known to be very approximately true.

Now by (10), which included only the external pressure, and by (22),

$$\tfrac{1}{2}\Sigma_1^n(A\theta'^2 + B\varphi'^2 + C\psi'^2) = \tfrac{3}{2}pv. \quad (23)$$

Hence, by (13) and (23) we have for perfect gases

$$\tfrac{1}{2}\Sigma_1^n(A\theta'^2 + B\varphi'^2 + C\psi'^2) = \tfrac{1}{2}\Sigma_1^n m(x'^2 + y'^2 + z'^2) \quad (24)$$

Equation (24) states that the mean progressive energy of the molecules is for perfect gases the same as their mean rotary energy. For imperfect gases, however, the energy of progressive motion differs very slightly from that of the rotary motion; a fact, the consequences of which will be more completely discussed in the latter part of this paper.

From this general statement of the equality of the mean rotary and progressive energy of the molecules, the special cases must, however, be excepted in which one or more of the couples L, M, N vanish identically. These couples may evidently all three so vanish when the molecules are in effect smooth spheres, and a single one of them may vanish in cases where the molecules may be regarded as smooth solids of revolution.

When $$L = M = N = 0$$

i. e., all three couples vanish, we have by (19)

$$\rho_1 = \rho_2 = \rho_3 = 0,$$

in which case equation (20) cannot be assumed to hold true. It appears, however, from (17) that in this case the energy of rotation about each axis vanishes.

In case a single couple, only, vanishes, let, for example, $L = 0$; then

$$\tfrac{1}{2}\,\Sigma_1^n (B\varphi'^2 + C\psi'^2) = -\tfrac{1}{2}\,\Sigma_1^n (yY' + zZ') = \tfrac{1}{2}\,\Sigma_1^n m (y'^2 + z'^2), \quad (25)$$

in which the first member is the mean total energy of rotation, and the last is two-thirds the mean total progressive energy, as is evident from the symmetry of the axes x, y, z.

Nothing has so far been said as to the amount of the kinetic energy of atomic vibration within the molecule, a question which we shall consider subsequently; but we may here remark that there is nothing in the preceding investigation of rotary motion which would lead us to restrict its application to those molecules alone in which A, B, C are constant, although it appears not unreasonable to suppose that the molecules of any substance are unchanged in their general character by change of state of aggregation, and that whether a substance be solid, liquid or gaseous, the molecules of which it is composed may be regarded as nearly rigid; *i. e.*, incapable of deformation to any considerable extent by finite forces, which is equivalent to supposing A, B, C nearly invariable. We shall therefore take the terms expressing mean energy of rotation to express mean values when the moments of inertia as well as the rotary velocities are subject to fluctuations of value consistent with the state of stationary motion.

That atomic vibrations do exist may be considered to be a fact from spectroscopic evidence, for the lines in gaseous spectra cannot be directly due to the very moderate progressive velocity of the molecules, but are rather to be ascribed to the intense vibrations set up within the

molecules by their mutual encounters, which vibrations would rapidly be extinguished by the energy they radiate, did they not also receive radiant energy from external sources.

Should any difficulties be felt as to admitting that the mean value of the last term but one in (16) vanishes, as was done in obtaining (17), it is to be noticed that whenever two of the moments of inertia of the molecule are equal, as for example $M = N$, then (17) hold from this consideration also, for then must the corresponding mean angular velocities be equal by symmetry, which with the equality of the two moments, M and N, is sufficient to insure the equalities expressed in (17).

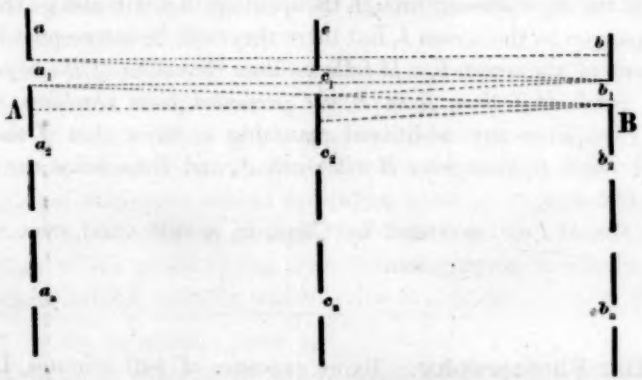
The hypothesis that $M = N$ must in many cases be correct, and it may perhaps be shown in all cases not to be far from the truth, when, as stated, (17) will hold for this reason alone.

(To be continued.)

SECOND LAW OF THERMO-DYNAMICS.

By De Volson Wood, M.A.

In the last number of this Journal is an article by Professor Eddy, in which he attempts to show how radiant heat may be made an exception to the second law of Thermo-dynamics; but it appears to us that the assumptions involve fallacies which are fatal to the proof.



We hold that it is *impossible* for a series of projectiles, or a train of projectiles, or a ray of light, or a ray of heat to pass from the body A freely through the opening of the screens and reach the body B as

claimed, and at the same time prevent those from *B* reaching *A*; and unless Professor Eddy can show that our position is erroneous, the supposed proof fails.

First, suppose that the mill is so constructed that the screen *c* will intercept all the rays from *B* passing through the openings b_1, b_2, etc., and are reflected back by the solid part of *c*.

Let all the spaces and openings be equal, and the screen *c* midway between *a* and *b*. The spaces in the screen *c* will not be exactly on the line of the openings a_1 b_1, but will be a little below that line, so that when all the screens are moved upward with the velocity and in the manner assigned by Professor Eddy, the spaces *c* will be on the line *A B* when the wave from *B* reaches *c*. Under these conditions no ray from *B* can pass the screen *c*. The rays being normal to the screens, it follows for the same reason that none of the rays from *A* can pass the middle screen if the openings in *a* are directly opposite those of *b*. If the openings in *a* are higher or lower than those in *b*, some or all of the rays passing through the openings in *a* will also go through *c* and pass on to the screen *b*, but there they will be intercepted by the solid part of the screen *b*. It follows then that *none of the rays from A can reach B if those from B are prevented from reaching A*. It scarcely requires any additional reasoning to show that *if the rays from A reach B, those from B will reach A*, and thus defeat the object of the inventor.

The *Second Law*, as stated by Clausius, is still valid, even with a finite velocity of propagation.

Stellar Photography.—By an exposure of 140 minutes, Draper has succeeded in photographing stars smaller than the fourteenth magnitude. He hopes to be able to photograph, ere long, stars which are too small to be seen in his nine-inch telescope.—*Les Mondes.* C.

PHOTODYNAMIC VIRIALS IN THE SOLAR SYSTEM.

By Pliny Earle Chase, LL.D.

The theory of the virial, or mean *vis viva* during stationary motion, enables us to co-ordinate all forms of cyclical motion, rotary, orbital and oscillatory. The grandest manifestations of the virial, which are given in cosmical motion, must be governed by the same laws as govern molecular movements. The complete development of the theory should, therefore, remove all the obscurity which still clings to the doctrine of radiodynamic unity.

A few cosmical illustrations will show the simplicity which considerations of mean energy introduce into the approximate solution of problems which would otherwise be exceedingly complicated. The illustrations are based upon the following postulates.

1. That cosmical masses represent internal energies, such as would be found if they were condensed from some primitive, tenuous, elastic form of matter.

2. That all chemical elements may have been condensed, in like manner, from a single primitive element, or æther.

3. That the velocity which enters into the primitive radial virial of the oscillating ætherial particles is the velocity of light (v_λ).

4. That the stationary motions of central inert masses, which represent the equal actions and reactions of primitive and derived virials, should continue until the velocity of the primitive virial has been alternately acquired and lost.

5. That all stationary motions which represent equal actions and reactions should be harmonic.

Solar or stellar centres of planetary systems, are central inert masses, which are endowed with velocities of stationary motion, tending to give velocities of stationary orbital revolution, sending forth æthereal oscillations with the velocity of light, and representing internal energies like those which would spring from nebular condensation.

Circular orbital velocity which is due to solar action, may be represented by the equation, $v_n = \sqrt{g_n r_n}$. 1

The limiting value of v_n, which it cannot exceed, is found at sun's surface ($r_\circ$), where g is a maximum. It may be represented by

$$[v_\circ] = \sqrt{g_\circ r_\circ} \qquad 2$$

The 3d and 4th postulates lead to the equation

$$g_\circ l_\circ = v_\lambda \qquad 3$$

This equation holds good for all values of r in an expanding or contracting nucleus, inasmuch as g varies as $\frac{1}{r^2}$, and the principle of conservation of areas requires that the time of rotation should vary as r^2. The product of the two factors should, therefore, be constant.

The rotating æthereal tendency of stationary motion, which is limited by equations (2) and (3), gives the following value for the limiting radius of orbital and æthereal tendencies.

$$\rho_\lambda = \frac{v_\lambda}{[v_\circ]} r_\circ = v_\lambda \sqrt{\frac{r_\circ}{g_\circ}} \qquad 4$$

Laplace's limit of equal rotary and orbital velocity (l) is given by the equation

$$l = \left(\frac{\rho_\lambda}{\pi r_\circ}\right)^{\frac{2}{3}} r_\circ = \left(\frac{\rho_\lambda r_\circ^{\frac{1}{2}}}{\pi}\right)^{\frac{2}{3}} \qquad 5$$

The limit at which the equatorial rotary velocity of stationary motion would give $[v_\circ]$ is

$$\left(\frac{l}{r_\circ}\right)^{\frac{3}{2}} r_\circ = \left(\frac{l}{r_\circ^{\frac{1}{3}}}\right)^{\frac{3}{2}} = \frac{\rho_\lambda}{\pi} \qquad 6$$

The limit at which the equatorial velocity of stationary motion would give v_λ, as deduced from (4) and (6), is

$$\left[l\right] = \frac{\rho^2_\lambda}{\pi r_\circ} \qquad 7$$

The limit of a homogeneous elastic æthereal atmosphere, which would propagate undulations with the velocity of light, is

$$M = \pi\,[l] = \frac{\rho^2_\lambda}{r_\circ} \qquad 8$$

The virials of rotating tendency must influence grosser inert particles or masses, as well as the æthereal atmosphere. Loci of important influence may be found at radii of mean æthereal momentum (ρ_α), of linear oscilation (ρ_β), of reciprocal linear oscillation (ρ_γ), of spherical oscillation (ρ_δ), and of reciprocal spherical oscillation (ρ_ε). Taking ρ_λ as the virial locus of these several oscillatory centres, we have

$$\rho_\alpha = 2\,\rho_\lambda \qquad 9$$

$$\rho_\beta = 1{\cdot}5\,\rho_\lambda \qquad 10$$

$$\rho_\gamma = 3\,\rho_\lambda \qquad 11$$

$$\rho_\delta = 2{\cdot}5\,\rho_\lambda \qquad 12$$

$$\rho_\epsilon = \tfrac{5}{3}\,\rho_\lambda \qquad 13$$

The tangential virial of an oscillating æthereal particle (μ_α), is $\frac{2}{5}$ of the radial virial of wave propagation for the same particle (μ_β). I first called attention to this relation in 1872.* Maxwell subsequently published it, apparently as an independent deduction, in 1877.†

$$\mu_\alpha = 1{\cdot}8\,\mu_\beta \qquad 14$$

An energy which is wholly transferred from one æthereal mass to another equivalent æthereal mass, must be accompanied by a like transfer of velocity, whether the transfer is through torsion (v_t), rotation (v_r), heat (v_θ), work (v_w), electricity (v_ε), or gravitation (v_γ).

We have, therefore, for limiting velocities,

$$v_\lambda = v_t = v_r = v_\theta = v_w = v_\varepsilon = v_\gamma \qquad 15$$

In cyclical movements which are due to virial transfers, these several equivalents may be indicated by equations analogous to (3).

In order to test the foregoing equations, let us take sun's semi-diameter ($r_\circ$) as the unit of length, and the British Nautical Almanac estimate of sun's apparent semi-diameter (961″·83) as the parallactic unit. We then find, for earth's semi-axis major,

$$\rho_\oplus = 214{\cdot}45\,r_\circ. \qquad 16$$

Earth's mean orbital velocity (1) may be found by dividing $2\,\pi\rho_\oplus$ by the number of seconds in a year (31558149). This gives

$$v_\oplus = {\cdot}000000199099\,\rho_\oplus \qquad 17$$

This value varies slightly with varying orbital eccentricity, but the greatest secular range of variation is less than $\frac{1}{8}$ of one per cent.

Circular orbital velocity varying inversely as the square root of the radius vector, we find (2) and (17)

* Proc. Amer. Phil. Soc., xii, 394. † P. Mag., iii, 453; iv, 209.

$$[v_\circ] = \cdot 00000291562\ \rho_3 = \cdot 000625255\ r_\circ \qquad 18$$

$$g_\circ = \cdot 0000003909445\ r_\circ \qquad 19$$

Struve's constant of aberration gives, by (3) and (19)

$$v_\lambda = g_\circ l_\circ = 214{\cdot}45\ r_\circ \div 497{\cdot}827 = \cdot 430772\ r_\circ \qquad 20$$

$$t_\circ = 1101876 \text{ sec.} = 12{\cdot}753 \text{ days} \qquad 21$$

This gives for a double oscillation, or complete rotation of sun, 25·506 days. Laplace's estimate was 25·5 days. The motion of sun-spots near the equator is accelerated, by centrifugal force, tendencies to orbital velocity, "repulsion," or some other unknown influence. Spörer's formula gives 24·62 days for the equatorial period.

From (4), (18) and (20) we find

$$\rho_\lambda = 688{\cdot}954\ r_\circ = 3{\cdot}212654\ \rho_3 \qquad 22$$

From (5) $\quad l = 36{\cdot}366\ r_\circ \qquad 23$

From (6) $\quad \rho_\lambda \div \pi = 219{\cdot}301\ r_\circ \qquad 24$

From (7) $\quad [l] = 151088{\cdot}1\ r_\circ = 704{\cdot}538\ \rho_3 \qquad 25$

From (8) $\quad M = 474657{\cdot}3\ r_\circ = 2213{\cdot}37\ \rho_3 \qquad 26$

From (14) and (22) we find the following regular series of approximations to planetary loci. The subscripts, 1, 2, 3, denote, respectively, secular perihelion, mean, and secular aphelion.

$1{\cdot}8^{-4}\ \rho_\lambda =$	$\cdot 3060\ \rho_3$	Mercury_1	$= \cdot 2974\ \rho_3$	27
$1{\cdot}8^{-3}\ \rho_\lambda =$	$\cdot 5509\ \rho_3$	Venus_1	$= \cdot 6722\ \rho_3$	28
$1{\cdot}8^{-2}\ \rho_\lambda =$	$\cdot 9916\ \rho_3$	Earth_2	$= 1{\cdot}0000\ \rho_3$	29
$1{\cdot}8^{-1}\ \rho_\lambda =$	$1{\cdot}7848\ \rho_3$	Mars_3	$= 1{\cdot}7365\ \rho_3$	30
$1{\cdot}8^{0}\ \rho_\lambda =$	$3{\cdot}2127\ \rho_3$	Asteroid 108	$= 3{\cdot}2120\ \rho_3$	31
$1{\cdot}8^{1}\ \rho_\lambda =$	$5{\cdot}7828\ \rho_3$	Jupiter_3	$= 5{\cdot}5193\ \rho_3$	32
$1{\cdot}8^{2}\ \rho_\lambda =$	$10{\cdot}4090\ \rho_3$	Saturn_3	$= 10{\cdot}3433\ \rho_3$	33
$1{\cdot}8^{3}\ \rho_\lambda =$	$18{\cdot}7362\ \rho_3$	Uranus_2	$= 19{\cdot}1836\ \rho_3$	34
$1{\cdot}8^{4}\ \rho_\lambda =$	$33{\cdot}7252\ \rho_3$	Neptune_3	$= 30{\cdot}4696\ \rho_3$	35
Geom'l Mean =	$3{\cdot}2127\ \rho_3$	Geom'l Mean	$= 3{\cdot}2200\ \rho_3$	36

All of these approximations represent loci of belt-condensation, for the respective planets, which are in accordance with the nebular hypothesis. The geometrical means differ by less than $\frac{1}{4}$ of one per cent. The photodynamic mean represents the semiaxis major of Asteroid 108; the planetary mean, the semiaxis major of Asteroid 122. The second photodynamic locus (.5509 ρ_3) is, within less than one per cent., the arithmetical mean between the semiaxes major of Mercury and Venus (·5552).

From (9), (10), (11), (12), (13), and (22) we get the following approximations:

ρ_α	$= 6{\cdot}4253\ \rho_3$	Cardinal centre	$= 6.4451\ \rho_3$	37
ρ_β	$= 4{\cdot}8190\ \rho_3$	Jupiter_1	$= 4{\cdot}8863\ \rho_3$	38
ρ_γ	$= 9{\cdot}6380\ \rho_3$	Saturn_2	$= 9{\cdot}5389\ \rho_3$	39
ρ_δ	$= 8{\cdot}0318\ \rho_3$	·4 Uranus_3	$= 8.2717\ \rho_3$	40
ρ_ϵ	$= 5{\cdot}3545\ \rho_3$	Jupiter_2	$= 5.2028\ \rho_3$	41
Ar. Mean	$= 6.8537\ \rho_3$	Ar. Mean	$= 6{\cdot}8690\ \rho_3$	42
Ge. Mean	$= 6{\cdot}6325\ \rho_3$	Ge. Mean	$= 6{\cdot}6421\ \rho_3$	43

It will be seen from (40) that the second locus of spherical rotary projection from ρ_λ, ($2{\cdot}5 \times 2{\cdot}5\ \rho_\lambda = 20{\cdot}0795\ \rho_3$), is within the secular orbital range of Uranus. The cardinal centre (37) is the centre of gravity, at conjunction, of Saturn_2 and Jupiter_3. It represents, therefore, the locus of mean rotary momentum for their combined masses, at the time of Jupiter's incipient rupturing subsidence, according to Herschel's modification of the nebular hypothesis. It also represents important relations to the following additional virial loci.

ρ_ζ	$= \sqrt{\Sigma m\rho^2 \div \Sigma m}$	$= 9{\cdot}2443\ \rho_3$	44
ρ_η	$= \Sigma m\rho \div \Sigma m$	$= 7{\cdot}5228\ \rho_3$	45
ρ_ϑ	$= \frac{1}{2}$ ($\text{Saturn}_2 + \text{Jupiter}_3$)	$= 7{\cdot}5291\ \rho_3$	46
ρ_ι	$= \frac{1}{2}$ (6·4451 + 8·2717)	$= 7{\cdot}3584\ \rho_3$	47
$\rho_\varkappa$	$= \frac{1}{4}$ Neptune_2	$= 7{\cdot}5084\ \rho_3$	48

The locus of mean planetary nebular inertia (44) is in Saturn's orbit, where the rings, the satellite system and the specific gravity bear witness to the results of nebular condensation. The locus of mean planetary nebular momentum (45) approximates closely to the arithmetical mean between Saturn_2 and Jupiter_3 (46), to the arithmetical mean between the cardinal centre and the incipient virial locus of spherical rotation for Uranus (47), and to the virial locus for the mean linear momentum of Neptune's semiaxis major (48).

The virial radius of mean momentum not only determines the centre of gravity of the two chief planetary masses (9), (37), but it also determines the relative masses of Sun ($m_\circ$) and Jupiter (m_5) at initial nebular rupture (secular perihelion). We find, accordingly,

$$m_\circ r_\circ = m_5 \rho_{5\prime 1} \qquad 49$$

Stockwell's estimate of Jupiter's secular eccentricity is .0608274. This gives $\rho_{5\prime 1} = \cdot 9391726 \times 5\cdot 202798 \times 214\cdot 45 = 1047\cdot 872\ r_\circ$. Therefore, (49)

$$m_\circ = 1047\cdot 872\ m_5 \qquad 50$$

Bessel's estimate is 1047·879. This harmony is the more significant because Jupiter's nebular locus of incipient rupture (4·8863) is central between the loci of incipient subsidence of Uranus (20·6792) and Neptune (30·4696) at opposition,

$$\rho_{5\prime 1} = \tfrac{1}{2}\,(\rho_{7\prime 3} - \rho_{6\prime 3}) \qquad 51$$

While Jupiter thus traverses the primitive nebular centre, Earth traverses the centre of the belt of greatest condensation.

$$\tfrac{1}{2}\,(\rho_{1\prime 1} + \rho_{4\prime 3}) \equiv \rho_3 \qquad 52$$

Stockwell's estimates for the secular limits of the dense belt (Mercury_1 and Mars_3) are, $\rho_{1\prime 1} = \cdot 2974$; $\rho_{4\prime 3} = 1\cdot 7365$. This gives for (52) $1.0169\ \rho_3$.

While the rotation of the chief nucleal centre (Sun) is determined by the velocity of light (3), the rotations of the secondary centres of nebulosity (Jupiter) and condensation (Earth) are determined, respectively, by circular orbital velocities at Sun's surface [$v_\circ$] and at the mean centre of gravity of Sun and Jupiter [v_*].

$$g_3 l_3 = [v_\circ] = \sqrt{g_\circ r_\circ} \qquad 53$$

$$g_3 l_3 = [v_*] = \sqrt{g_* r_*} \qquad 54$$

The data for the solution of (54) have been more accurately and satisfactorily determined than for (53).

$$g_3 t_3 = \frac{32{\cdot}088}{5280} \times \frac{86164{\cdot}08}{2} = 261{\cdot}821 \text{ miles.} \qquad 55$$

Circular orbital velocity varying inversely as $\sqrt{r}$, we find (49), (50), (54), (55)

$$g_5 t_5 = [v_0] = g_3 t_3 \div \sqrt{.9391726} = 270{\cdot}167 \text{ miles.} \qquad 56$$

$$[v_3] = [v_0] \div \sqrt{214{\cdot}45} = 18{\cdot}449 \text{ miles.} \qquad 57$$

$$\rho_3 = 31{,}558{,}149\ [v_3] \div 2\pi = 92{,}662{,}000 \text{ miles.} \qquad 58$$

$$r_0 = \rho_3 \div 214{\cdot}45 = 432{,}090 \text{ miles.} \qquad 59$$

At Earth's surface, $\sqrt{gr} = 4{\cdot}9073$. It varies as $\sqrt{\frac{m}{r}}$. Therefore,

(57)

$$\frac{m_0}{\rho_3} : \frac{m_3}{r_3} :: 18{\cdot}449^2 : 4{\cdot}9073^2 \qquad 60$$

$$m_0 : m_3 :: 330482 : 1 \qquad 61$$

All of the results which have been drawn from (3), (53), and (54) involve the principle of persistency of vibrations, by which waves tend to propagate themselves indefinitely, with the velocity which is due to their locus of origination.

The influence of Jupiter's locus of incipient subsidence on the comparative masses of Jupiter and Saturn, finds some analogy in the two chief planets of the dense belt, Earth and Venus.

$$m_2 \rho_{2\cdot3} = m_3 \rho_3 \qquad 62$$

Substituting Stockwell's estimate of the secular aphelion of Venus ($\rho_{2\cdot3} = {\cdot}7744234\ \rho_3$) in (61) (62),

$$m_0 = 426750\ m_2 \qquad 63$$

Hill's estimate is 427240, which differs from (63) by less than $\frac{1}{8}$ of one per cent.

The general equation of fundamental velocity (15) rests on Laplace's principle of periodicity, "that the state of a system of bodies becomes periodic when the effort of primitive conditions of movement has disappeared by the action of resistances." Hence (3) (20),

$$v_\lambda = v_\gamma \qquad 64$$

The investigations of Weber, Kohlrausch, Thomson, Maxwell, Ayrton, and Perry have shown that

$$r_\lambda = v \qquad 65$$

In Coulomb's formula of torsional elasticity, if we substitute $\frac{m}{2}$ for f, $gt^2 = M$ (26) and

$$gt = \dot{v}_{\lambda} = v_{t} \qquad 66$$

In throwing a ball into the air, the thermal equivalent of the projectile force is equivalent to the product of the mass by the sum of the retarding resistances. In solar superficial radiation, the gravitating reaction, as we have seen (64), is exhausted in a half rotation. The corresponding projectile velocity may be regarded as representing, at pleasure, heat, work or rotation, giving

$$v_{\lambda} = v_{\theta} = v_{w} = v_{r} \qquad 67$$

Combining (64), (65), (66), (67), we find a practical confirmation of (15).

A NOTE UPON THE WORKING OF SULPHURIC ACID CHAMBERS.

By Henry Pemberton, Jr.

[A paper read before the Chemical Section of the Franklin Institute, March 13, 1883.]

During several years subsequent to the panic of 1873 a set of acid chambers, the property of a company of this city, was worked under my supervision. Owing to the depressed state of trade and consequent stock of goods on hand, the chambers were often run below their full capacity. They were run without a Gay Lussac absorbing tower, and burned best unmixed seconds brimstone, 4,000 pounds being the normal charge in 24 hours. Good results, approaching very nearly to the theoretical figures were obtained from such a charge when 10 per cent. nitre was used. Burning 3,600 pounds per day, 9 per cent. nitre was required, and with 3,000 pounds, 8 per cent. As the cubic capacity of the set was 107,200 cubic feet, the following represents the pounds sulphur, per cent. nitre, and cubic feet per pound sulphur.

Pounds sulphur.	Per cent. nitre.		Cubic ft. per pound sulphur.
4,000	10	=	26.8
3,600	9	=	29.8
3,000	8	=	35.7

Several years after this the capacity was nearly doubled by the addition of two more chambers, the whole being run in one set, with a

Gay Lussac and Glover—still burning brimstone. The total number of cubic feet was now 202,600, the towers and connecting pipes not being included. Sulphur charged was about 10,500 pounds a day, per cent. nitre from 3 to 3½.

The following gives the totals of four weeks running (28 days), being a fair illustration of the workings of the chambers when in good condition:

Total sulphur burned	295,265 pounds.
" nitre potted	10,005 "
No. of blowups of nitrous acid run through the Glover	325 "

Dividing these figures by 28, we get as the daily average:

Sulphur burned	10,545 pounds.
Nitre potted	357 "
Blowups of nitrous vitriol through the Glover	11·61 "

The test of this nitrous vitriol was made with permanganate, using 5 cc. of solution, containing 15·8 grams $KMnO_4$ per litre, (= ½ normal.)

The nitrous vitriol was run into this from a graduated pipette, the volume required varying from 1·2 cc. to 1.5 cc. Adding up the total tests made in the above 28 days, I find that as a daily average 1·352 cc. nitrous vitriol exactly decolorized the 5 cc. of permanganate. It results from this that 100 pounds nitrous vitriol contains N_2O_3, equivalent to 4·62 pounds of chemically pure nitrate of soda. 11·61 blowups of this went daily through the Glover, each blowup delivering 2,334 pounds 1·7 specific gravity acid. Hence, total nitrous vitriol = 27,097 pounds at 4·62 per cent. = 1,252 pounds pure $NaNO_3$ = 1,291 commercial 97 per cent. nitrate.*

Hence the chambers were charged with nitre as follows:

From Glover	1,291 pounds.
" nitre pots	357 "
Total	1,648 "

This 1,648 pounds, nitre = 15.62 per cent. of the weight of the sulphur (10,545), and the chamber capacity (202,600 cubic feet) = 19.2 cubic feet per pound sulphur.

*The acid after it had passed through the Glover was tested to see if it had any action on the $KMnO_4$, with practically negative results, proving that the acid had been completely denitrated, and was free from foreign reducing substances.

Combining this with results from old set of chambers, we have:

Sulphur burned.	Per cent. nitre.	Cubic ft. per pound sulphur.
4,000	10	26.8
3,600	9	29.8
3,000	8	35.7
10,545	15.62	19.2

The above shows the proportion of the two variables; nitre and cubic feet per pound sulphur, under widely different circumstances. For the nitre varied from 8 to over 15½ per cent., and the cubic feet from 35·7 to 19·2, the increase of one being proportionate to the decrease of the other.

This being the case the product obtained by multiplying the two together should be nearly a constant quantity, as follows:

$$10 \times 26{\cdot}8 = 268$$
$$9 \times 29{\cdot}8 = 268$$
$$8 \times 35{\cdot}7 = 285$$
$$15{\cdot}62 \times 19{\cdot}2 = 300$$
$$\text{Mean.} = 280$$

To give an illustration of the meaning of figure 280: a chamber with 280 cubic feet capacity per pound sulphur would require 1 per cent. nitre, one with 140 cubic feet would require 2 per cent., with 28 cubic feet 10 per cent., with 14 cubic feet 20 per cent., and so on.

It is not to be expected that any formula based upon such changeable *data* as are furnished by the gases of an acid chamber, will give absolutely unvarying results. Changes of the seasons of the barometer, of temperature, of the direction of the wind, of the steam pressure, and from a hundred local sources cause the result to vary within certain limits. Although the figures given above are derived only from this one particular set of chambers, and although it would be very interesting to have corroborative proof from other experiences, nevertheless it must be remembered that the above trials extended over a number of years, and were made under very widely different circumstances. They were made when the capacity was only about 100,000 cubic feet, and again when it was double this; when the chambers were running without towers, and later when both Gay Lussac and Glover were present. Therefore, since in all these cases the resulting figures were closely accordant, they may be accepted by any manufacturer as a check upon the working of his chambers.

The chamber capacity in cubic feet, multiplied by the per cent. nitre

used, and divided by the number of pounds of sulphur burned daily should give a result not far from 280, and all the better if it approaches to 300. If the result falls considerably below the former figure, it is a pretty safe indication towards a low yield in acid, and a consequent loss in dollars and cents.

THE GEOLOGY OF PHILADELPHIA.

By Professor H. Carvill Lewis.

[A lecture delivered before the Franklin Institute, January 12, 1882.]

The formations upon which the city of Philadelphia is built may be divided into two great classes—the superficial formations and the underlying rock strata. The former of these, much the most recent of the two, are for the most part closely connected with the "Great Ice Age" which formed the subject of the lecture given one week ago. A description was then given of the ice-covered area of Pennsylvania, and of the numerous phenomena of glacial action which pertain to that region. The extent and the causes of glaciation were discussed, and an attempt made to arrive at some idea of its age. The great glacier which covered the whole northeastern portion of our continent, and which, as a great sea of ice, flowed in a continuous stream across Labrador, the Laurentian highlands of Canada, the Adirondacks, the Catskills and the Alleghanies, was proved to have finally stopped within sixty miles of our city. At the extreme edge of the glacier it heaped up a terminal moraine, composed of rock fragments brought from more northern regions, which moraine was shown to stretch in a continuous line completely across our State.

Directing our attention now to the rivers which cut through the moraine, it will immediately be evident that, at the time of the melting and retreat of the great glacier, these rivers must have been swollen to great dimensions by the floods which then rushed down them. They constituted the drainage courses for the waters of the melting glacier. Our spring freshets are nothing in comparison to the mighty torrents into which these rivers must have then been converted. These torrents brought down immense masses of loose material made by the glacier, while at the same time they tore up and carried down stream loose rocks all along their beds. When at last the flood subsided there remained as witnesses of its extent the clays, the gravel and

the cobblestones which we are about to study in detail. Among the rivers which brought down these deposits were the Delaware, the East branch of the Susquehanna and the Alleghany.

On the other hand, as may be seen by reference to the map of the moraine, the Schuylkill and the west branch of the Susquehanna did not issue from glaciers, their source being south of the moraine. It is now evident, therefore, why there are no drift deposits in the valleys of the last-named rivers, while on the other hand such deposits are of great extent in the river valleys first named.

A small portion of the superficial deposits of that part of the Delaware which lies between Trenton and the sea is due to marine or estuarine action, being more ancient than the deposits of glacial times.

In entering upon an examination of the geological formations of any place, the first step is the construction of a geological map. This we may proceed to do in our city as follows:

THE UPLAND TERRACE.

1. A traveler going from the city upon the Germantown Railroad will notice in the cuttings for new streets between Tenth and Broad streets, and in the railroad cut at New York Junction, numerous exposures of red or yellow gravel, often overlaid by clay. The brickyards in the vicinity of Nicetown expose large beds of brick-clay, containing occasional well-rounded boulders and pebbles. The land so far has been comparatively level, and no rocks have been seen. Just before reaching Wayne Junction, rocks rise upon both sides of the road, the clay and gravel disappear, and a rolling wooded country is entered. A thin covering of light micaceous soil, containing no pebbles or boulders, covers the gneissic rocks from here to Chestnut Hill. There is a great contrast between the two regions.

2. On the Pennsylvania Railroad it will be noticed that, soon after leaving the depot, gravel covers the rocks along the Schuylkill, and as the railroad turns back from the river, a plateau of clay follows. The Centennial grounds lie upon this clay, and boulders are frequent, a good section being exposed near the bridge at Belmont avenue. Upon reaching Fifty-seventh street, opposite Belmont and George's Hill, the hill is entered by a cut, the rocks come to the surface, and the drift is no more seen.

3. Again, on the North Pennsylvania Railroad gravels first appear,

then, on higher ground, clay, and soon after passing Green Lane Station, the rocky uplands, free from drift.

4. So, too, on the West Chester Railroad, gravels and clays cover the ground up to the base of the hill on which Swarthmore College stands.

5. On the other hand, the New York division of the Pennsylvania Railroad and the Philadelphia, Wilmington and Baltimore Railroad, which run parallel with the Delaware river, do not rise out of the region of drift.

Now, connecting by a line the four points mentioned, it will be found to represent a long straight hill, 200 feet or more in height, having a northeast and southwest trend, parallel to the river, and lying at a mean distance from it of about four miles. The speaker has traced it, through Bucks, Philadelphia and Delaware counties, into the State of Delaware, and finds that it uniformly defines the western boundary of the drift. This hill is easily recognized, where uncrossed by creeks, being remarkably straight and of uniform height. It forms the limit of tide-water, and is recognized where it crosses streams by the occurrence of rapids or falls. Being the first hill of importance west of the Delaware, it often commands a fine view, and is a favorite site for residences. The geographical position of this ancient terrace may be more exactly defined in the vicinity of Philadelphia as the hill which crosses Second street pike near Foxchase, and, crossing Tacony creek farther south, runs nearly parallel with it as far as Crescentville; which crosses Green lane and New Second street road near the place of Mr. J. L. Fisher; crosses the North Pennsylvania Railroad above Olney road, and the York road below the Jewish Hospital; which crosses Germantown avenue at the railroad bridge (being here called Negley's Hill), and running along the railroad to beyond Wayne Station, passes back of the Germantown Cricket Ground, past Old Oaks Cemetery, to Falls of Schuylkill. Thence, passing Chamouni, Belmont and George's Hill, it crosses the Pennsylvania Railroad near Hestonville, and Haverford road at Haddington; passes back of the Burd Orphan Asylum into Delaware county, and runs north of Kelleyville, Clifton and Morton to Swarthmore College, and thence, past Village Green, into Delaware.

North of Philadelphia, this hill may be followed through Bucks county, past Somerton, to the Neshaminy creek, when it crosses the Bound Brook Railroad, and then bends back to form the hill back of

Yardleyville. This hill, which is approximately parallel not only to the river, but also to the shore of the Atlantic Ocean and to the line of strike of the Cretaceous formations of New-Jersey, forms, as we have seen, the main dividing line between the ancient and the modern formations.

The speaker has called it for convenience the *Upland Terrace.* The strike of the gneiss forming it corresponds closely with the trend of the terrace itself. A boulder-bearing clay rests upon its southeastern slope, at a uniform elevation of 150—180 feet above mean ocean level. While it is true that, as will appear hereafter, there are patches of an ancient gravel on high points back of it, the Upland Terrace nevertheless remains as the most important geological feature in southeastern Pennsylvania.

Between the Upland Terrace and the Delaware, clays and gravels cover the rocks in a continuous sheet except where eroded away in the neighborhood of streams. The amount of their erosion is in some respects a measure of the age of the surface formations. These formations in the vicinity of Philadelphia have undergone very different amounts of erosion, the amount of such erosion increasing as we recede from the Delaware; and this fact offers evidence that the deposits are of different ages; those lying farthest from the river and highest in elevation being the most ancient, and those which are close to the river, which have undergone but little erosion, being the most modern of our surface formations. Examples of erosion of the Philadelphia gravel may be well seen on the Philadelphia and West Chester Railroad, which crosses a number of creeks and runs nearly parallel to the terrace for several miles. As each creek is approached the drift disappears and rocks come to the surface. So, on the Schuylkill, no gravel is seen on the river drive in the East Park, but, upon going back from the river and rising 100 feet above it, as far as the East Park Reservoir, gravel appears abundantly. Yet, on the same river, nearer the Delaware, a newer gravel, made of different materials, not only forms its banks but underlies it.

RECENT ALLUVIUM.

The most recent of all the surface deposits is the stiff bluish clay which covers the low ground in the southern part of the city. The Richmond meadows and the flats of Moyamensing, Greenwich and Tinicum are covered by this deposit. It is bounded by a low ter-

race, which is from 10 to 15 feet above tide. This terrace, up to which the river often comes in times of flood, crosses South Broad street diagonally below Moyamensing avenue, and, crossing the Delaware extension of the Pennsylvania Railroad, near Penrose Ferry road, winds around Point Breeze Park back towards the Gas Works, and, passing below Suffolk Park, crosses into Delaware county. Sometimes, as in Tinicum, certain islands of older gravel, rise out of the mud-flats. The blue clay of this formation is too stiff to be useful for brickmaking. Blackened fragments of twigs, roots and leaves are frequent in it, and it is said that trunks of the white cedar abound in it in some places. There is here an indication that these beds are sinking and that, as on the Atlantic coast, the water is encroaching. Frequently a good peat covers the clay. Artesian well records show that this blue mud at Frankford is 24 feet deep. Generally it is much shallower, and is underlaid by a sand, the formation next older.

THE TRENTON GRAVEL.

A light sand and gravel, free from clay, underlies the blue clay just mentioned, and extends considerably farther back from the river. It is composed principally of a sharp micaceous sand, which, when below water-level, becomes a "quicksand." Gravel lies below the sand. Unlike all the other gravels, it contains but few pebbles of white quartz, and is of a dark gray color. Its pebbles are made exclusively of the rocks forming the upper valley of the river. Their shape is also very characteristic. The pebbles of the older gravels are oval or egg-shaped, but these are for the most part flat. This flat shape is characteristic of all true river gravels. At several places along the Delaware, gold has been obtained from this gravel. The absence of clay in any of its layers indicates the action of swiftly running water. Data obtained from artesian wells have shown that this formation has a depth on Delaware avenue of about 50 feet, and that it extends up to about Third and Market streets. On Smith's Island and on the bar in the river opposite Cooper's Point it is 100 feet deep, lying upon rock. It therefore underlies the river, filling up its ancient channel. On Richmond street some very large boulders are seen lying upon the sand. Bridesburg and the Lazaretto are built upon it, the latter formerly an island surrounded by bog clay. The sand is used for building purposes. It is bounded by a terrace, which rises some 25 feet above mean tide, and is capped by the red gravel

and brick clay about to be described, while rocks are frequently exposed at its base. The Chester branch of the Reading Railroad lies below this terrace, and the present line of the Philadelphia, Wilmington and Baltimore Railroad is above it. This sandy river gravel forms islands in the blue mud. It forms a level plain, and lies in a channel-cut, the older formations to rock. It evidently formed the ancient river bed.

This last and newest of all the gravels is one which at Philadelphia seems to be of little importance. It lies close along the river, and, rising a few feet above it, extends but a short distance back from the river bank. Yet, from its great development farther up the river, and more especially from the fact that in this formation, and in this formation only, have traces of ancient man been discovered, it acquires great interest, and we are tempted to inquire more fully into its boundaries, its age and its origin.

On tracing this gravel up the river, it is found that, from Philadelphia to the Neshaminy Creek, its boundary is generally between the line of the Pennsylvania Railroad and the Delaware. From this point the bounding terrace trends directly towards Morrisville and away from the present river. Thus, at Bristol, the gravel and its overlying sand extends two miles back from the river, and is bounded by a well-marked hill, upon which lie older gravels and brick-clays. These and the Tertiary gravels extend nearly seven miles inland. At Tullytown our formation extends two and a-half miles back, and at the canal shows the following succession of strata: (1) sandy loam, 1 foot; (2) fine gray "moulding-sand," 2½ feet; (3) sharp "bar-sand," 1 foot; (4) clean gray river gravel of unknown depth. In other openings near here the gravel is so full of boulders that these are dug in large quantities and sent to Philadelphia for "cobble-stones." Near Wheatsheaf Station, close to the railroad, an opening which has exposed a section of the gravel nearly half a mile in length, exhibits well the general features of the formation. The pebbles, of characteristic shape and color, are made of gray Triassic argillite, slate, red shale, sandstone, conglomerate, and various other rocks found farther up the valley, while large and often sharp boulders of red shale and other materials frequently occur. The whole formation has a very fresh appearance when compared with older gravels. Near Turkey Hill a large smooth boulder, five feet in diameter, lies upon the sand.

Upon reaching Trenton, we find an immense outspread of the gravel,

and numerous fine exposures of it, both on the river bank and in the long cuts made by the Pennsylvania Railroad. The formation may therefore be designated for convenience the "*Trenton Gravel.*"

Trenton is in a position where naturally the largest amount of a river gravel would be deposited, and where its best exposures would be exhibited. It is at the point where a long, narrow valley with precipitous banks and continuous downward slope, opens out into a wide alluvial plain at a lower level. It is here that the rocky floor of the river suddenly descends to ocean level and even sinks below it, forming the limit of tidewater. Thus any drift material which the flooded river swept down in its channel would here, upon meeting tidewater, be in great part deposited. Large boulders which had been rolled down the inclined floor of the upper valley would here stop in their course, and all be heaped up with the coarser gravel by the more slowly flowing water except such few as cakes of floating ice could carry oceanward. On the other hand the finer gravel and sand would be deposited farther down the river.

This is precisely what occurs at Trenton. The material, which at Philadelphia is generally fine, grows coarser as the river is ascended, until at Trenton we find often immense boulders imbedded at all angles in the gravel. Moreover, the river has here cut entirely through the gravel down to the rock, exposing at one place a cliff of gravel 50 feet high. At Philadelphia, on the other hand, as we have seen, the river still flows on the top of the gravel. This fact may also be accounted for. Having heaped up a mass of detritus in the old river channel as an obstruction at the mouth of the gorge, the river, so soon as its volume diminished, would immediately begin wearing away a new channel for itself down to ocean level. This would be readily accomplished through the loose material, and would be stopped only when rock was reached. On the other hand, that gravel which had been deposited at places farther down the river where its bottom was below ocean level, would remain un-eroded or nearly so. When the river had attained the level of the ocean there would be no occasion to cut a deep channel, and it would therefore flow on top of the gravel which it had deposited.

The fact of the river having cut through the gravel at Trenton, while at Philadelphia it flows upon it, is due to the configuration of the rock floor of the river, which at Trenton rises above ocean level, and at Philadelphia lies nearly 100 feet below it.

At the time of the flood which deposited the Trenton gravel, the lower part of Philadelphia, the whole of Bristol and Tullytown, and almost all of Trenton were submerged. That the climate was then cold is indicated not only by the suggestion that there were then probably very large masses of boulder-bearing ice floating in the river, but also by the fact that, as stated by Dr. C. C. Abbott, bones of Arctic animals (walrus, reindeer, mastodon), often rounded by attrition, have been found in this gravel. The boulders resting upon the sand overlying the gravel suggests the grounding of large ice-cakes derived from some mass of ice large enough to be called a glacier.

It is difficult to imagine an origin for such a flood as we have described other than the melting of a glacier. This flood was not an inroad from the sea, but it came down the valley. Terraces of the same gravel may be traced above Trenton up the valley of the Delaware into the glaciated region above Belvidere. At Stroudsburg it is probably the same gravel which forms the well-marked terraces about the town, and there is every proof that the age of this formation is that immediately following the final retreat of the great glacier.

THE PHILADELPHIA BRICK CLAY.

The built-up portion of the city stands upon an extensive deposit of brick clay and gravel, sections of which are exposed in every cutting. The brick clay invariably overlies the gravel, and will therefore be first described. By far the finest exposures of brick clay are those on either side of Long lane, in the "Neck." The clay here is very compact, free from sand and gravel, and is often 15 feet or more in depth. Loam lies above it, and is mixed with it for brick-making. Well-rounded boulders of Potsdam, Medina, Trias, etc., are frequent. The whole lies upon some 20 feet of stratified gravel. It is a much finer and deeper clay than that of the northern part of the city, as at Nicetown. It is interesting to note that while the clay which is farthest from the Upland Terrace and lowest in elevation is purest and deepest, on the other hand that near the terrace, and more than 100 feet above the river, is both shallow and sandy. It suggests that the former was deposited in deep water and the latter near the shore. At the base of the terrace the clay is but two or three feet deep. The boulders of the Nicetown clay are similar to those of the Neck clay, except in the fact that in the latter there are numerous rounded and sharp fragments of triassic red shale, while in the former boulders of that material are

very scarce. The boulders of both clays are invariably derived from a northern source. No shells or organic remains have as yet been noticed in this formation, and it is therefore inferred both that the water was fresh and that it had a temperature too low to support life.

In the collection of boulders from this clay made by Mr. Eli K. Price, and deposited in the University grounds, many of the rocks which occur along the Delaware from Trenton to beyond the Water Gap are represented. Some of them are derived from the Terminal Moraine. The lecturer has been able to trace almost all of them to their source. He has also traced the boundaries of this boulder bearing clay up to the glaciated region, and finds that it uniformly rises to a fixed limit of 150 to 180 feet above the river. Where the valley is wide, as at Philadelphia and Trenton, the clay is pure and fit for brick-making, but in narrow and steep portions of the valley the current has been too swift for the deposition of clay and it is represented by occasional, stranded, waterworn boulders. This clay rests against the upland terrace from Trenton to Philadelphia, at an elevation of 150 feet. On the Lehigh river, a tributary of the upper Delaware, where the bed of the river is more than 200 feet higher than at Philadelphia, the clay rises 180 feet above the river. That this was an epoch of submergence is indicated by the elevation of the deposit. While the underlying gravel was deposited by a rushing flood, it was not until quieter conditions had prevailed that clay could be formed. It is probable that this clay may be assigned to a period when the land stood 150 feet or more below its present level, and when the cold waters from the melting glacier bore ice rafts which dropped their boulders.

These boulders are often of large size. Thus in Philadelphia there are smooth boulders of Silurian rocks between 4 and 5 feet long, at an altitude of a 100 feet above the river; and on the Lehigh above the Gap, we have found a boulder six feet long, elevated 150 feet above the river at that place. In the vicinity of Bethlehem, thirty miles below the Terminal Moraine, the boulders in the clay sometimes show glacial striæ. It hardly admits of doubt that these boulders were borne by large cakes of floating ice derived from the base of the melting glacier. Finally, it is of interest to find that the clay which cements the unstratified "*till*," the "ground Moraine" which covers the glaciated region to the north, is of a character so similar to the Philadelphia brick clay, that there is a strong probability that the

latter was derived, in great part, directly from the grinding base of the glacier. The Philadelphia brick clay becomes more and more stony as we proceed northward, until in valleys at the base of the Terminal Moraine of the glacier its stones are almost as numerous as those of the true glacial till. Deposits of this boulder-bearing brick clay have more than once been confounded with glacial moraines. The latter, however, as is well known, may be distinguished by the abundance of angular and ice-scratched boulders and by the absence of stratification.

THE RED GRAVEL.

Beneath the clay, and often unconformable with it, is the Philadelphia red gravel. It is a clayey gravel which packs well and is much used on roads, and whose red color is caused by the ferruginous clay in which the pebbles are imbedded. The pebbles are composed of all kinds of rock and are not flattened as are those in the river gravel. The predominant material is white quartz, but pebbles of all other materials, as conglomerate, sandstone, fossiliferous hornstone, flint, red shale, etc., are numerous. Stratification is observed in almost every section exposed. Good sections of gravel are seen near the University of Pennsylvania. It has here an elevation of about 50 feet, and comes to the surface of the ground with but a very slight covering of clay.

The clay almost always lies in the form of crests and hollows upon the gravel. Beautiful examples of wave motion may be seen at Twenty-eighth Street and Columbia Avenue, at Tenth and Tioga, at Fifteenth and Clearfield Streets, in Fairmount Park, at the Penna. Railroad cuttings near Belmont Avenue, and in many other places. In each of these we have apparently the action of a rushing flood of water upon the gravel. Often the clay lies in a kind of pot-hole in the gravel, and a concentric structure of clay and pebbles can be seen. At Twenty-eighth Street and Columbia Avenue six well-marked waves of gravel and clay may be seen, the clay always filling the hollows between the crests of gravel. Along the line of contact between clay and gravel there are alternate streaks of fine and coarse gravel.

A very beautiful example of water action is exposed at Fifteenth and Clearfield Streets, in a cut about one hundred feet in length.

Another point to be noticed in the section near the University is the stratification of the gravel, and its division into layers of three different colors,—red, black and yellow. It is instructive to note that this division is by no means a local one, but exists along a line of about

equal elevation (60 to 80 feet above ocean level), in widely separated parts of the city. While the colors are of course due simply to different states of oxidation of the iron, the fact that they mark continuous deposits through long distances, indicates a uniformity in the condition of deposition which could be due only to the presence of a large body of water.

The gravel rests, not upon a hard floor of rock, as is usual with the drift in more northern States, but upon a completely decomposed gneiss. This is universally the case in every section examined in the vicinity of Philadelphia.

The lower part of the gravel often consists of a sharp, stratified, micaceous sand, made up of the materials of the decomposed gneiss. Exposures in the East Park and along the line of the North Pennsylvania Railroad illustrate this fact. It is evident, therefore, that the gneiss was decomposed before the deposition of the gravel, and that water, not ice, was the agent of that deposition. The idea that a glacier once overrode the site of Philadelphia and deposited gravels and boulders has recently been urged by a Philadelphia geologist* but is not sustained by the observed facts. In fact there is no trace of glacial action in Pennsylvania, anywhere south of the terminal moraine, notwithstanding all statements to the contrary hitherto made by other geologists.

The red gravel was deposited by a flood of the ancient Delaware, at a time when it flowed at a level over 100 feet higher than at present. It is closely of the same age as the brick clay, both having been formed during or at the close of the glacial epoch. Many facts go to prove that the red gravel and the brick clay were formed at the time when the glacier began to retreat from its terminal moraine, the ground being then depressed about 180 feet, while the Trenton gravel, which flows in a channel cut through these deposits was formed long afterwards when the last lingering remnants of the glacier were thawed out, and when the land had risen to about its present elevation.†

*Mr. Hall, (Proc. Amer. Philos. Soc.) who concludes "that this belt of drift deposit is no other than a glacial moraine formed by the Schuylkill glacier receding from the site of the city."

† A map was here exhibited of the boundaries of the surface formations of Philadelphia, as traced out by Professor Lewis. He showed that these formations were confined to the river valley, being bounded by the "Upland terrace," and that they appeared on both sides of the river. He showed also that during part of the Glacial Epoch the Schuylkill emptied into the

THE YELLOW GRAVEL.

Nearly the whole of Southern New Jersey and a small adjoining portion of Pennsylvania are covered by a deposit of yellow gravel which has been variously known as quaternary, southern drift, etc. It extends southward all along the Atlantic coast in the region of tide water, rising some two hundred feet above the level of the ocean. It caps the watershed between the Atlantic and the Delaware (elevation 190 feet), and is well exposed in the railroad cuts at Glassboro and other places in New Jersey. This gravel, unlike those so far described, is not confined to the Delaware valley, but occurs all along the Atlantic seaboard in the Southern States. It is therefore of oceanic origin.

It is characterized by small water-worn pebbles, somewhat egg-shaped in form, seldom above an inch in length, usually less, and composed of quartz or quartzite rocks. There are also occasional pebbles of flint, and of fossiliferous hornstone and chert. It contains no large boulders, and has no pebbles of soft or readily decomposable rocks, and its pebbles have nearly all a weather-worn eaten appearance. Still other circumstances, such as the great amount of erosion it has suffered, and the decomposed state of the beds upon which it lies, point to the conclusion that it is an ancient deposit of marine origin, made during a submergence in preglacial times. The glacial drift overlies and is more recent than this yellow gravel. This gravel is of a yellowish color, becoming white when exposed to the weather, and is more sandy than the red gravel. For these reasons it is less esteemed for road making. The Germantown railroad cuts through this gravel at New York junction. The speaker has found here pebbles containing cyathophylloid corals, favosites, a trilobite, etc. The connecting railroad at Ridge avenue station cuts through the same gravel, and here occur *strophomena*, etc. Other fossils have been found below the clay in the East Park and at the Centennial Grounds. Pebbles of triassic red shale, so common in the red gravel, do not occur in this older yellow gravel.

The yellow gravel, which can always be recognized by the fossiliferous pebbles of Niagara limestone, etc., in it, may be studied on Darby

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Delaware at the Falls of Schuylkill, and that the State house steeple would then have been completely submerged. He spoke of the gold, which, in small quantity, disseminated throughout the clay, stating that it has been estimated that $126,000,000 of gold lies underneath the paved part of the city, and many times more within its corporate limits. He also described the process of brick making.

road, near the horse car depot, in the railroad cut at Ridley Park, Delaware county, where corals and other fossils abound, and in many other places in and about the city. It generally occurs near the base of the upland terrace upon a plateau covered by more recent brick clay. It is from this oceanic gravel that most of the pebbles of the red gravel have been derived. The yellow gravel is probably of *newer Pliocene* age.

THE BRYN MAWR GRAVEL.

Upon the summits of some of the highest hills in the gneissic region back of Philadelphia, at a mean distance of about nine miles from the river, and at elevations of from 325 to 450 feet above it, there are isolated patches of an ancient gravel, different from any yet described, to which the speaker has given the provisional name of "The Bryn Mawr Gravel." It can always be recognized by the presence of sharp or partially rounded fragments of a hard, heavy iron sandstone or conglomerate. Such fragments are often covered by a brownish black iron glaze. More than fifteen years ago, the speaker noticed in the soil of the upper part of Germantown, pieces of this conglomerate, unlike any known rock, and it is only of late that its origin has been suspected. It consists of well-rounded pebbles of quartzite or siliceous sandstone cemented by iron into a stone which is often very hard. This conglomerate is found in occasional fragments upon ground over 300 feet high, but is not found in abundance until an elevation of over 400 feet is reached. At these highest points it occurs in a red gravel whose pebbles are identical with those of the conglomerate.

One of such points is near Chestnut Hill, on the city line road at its highest elevation, near Willow Grove road. Here, nearly nine miles from the river and 425 feet above it, is a patch of this gravel and conglomerate, in which sharp fragments of quartzite are numerous, but there are no traces either of triassic red shale, of fossiliferous pebbles, or of rounded pebbles of the underlying gneiss.

A similar tract of this gravel occurs at Bryn Mawr, extending from that place to near Cooperstown. A good section is exposed in the railroad cut below the station. From this locality the formation is named. It is here about 430 feet high, and nine miles from the river. The gravel is ten feet deep, and lies upon a steeply-dipping gneiss so completely decomposed that it is as soft as clay. Here, as at Chestnut Hill, the gravel lies in an isolated patch upon a hill, distant from any

stream or other eroding agency. The gravel holds sharp fragments of primal rocks, and also the iron conglomerate. As at Germantown, the fields below, to the south, contain occasional fragments of the conglomerate.

Another good exposure of the Bryn Mawr gravel is on a hill crossed by the road leading from Haverford College to Cooperstown. The conglomerate is here in large, sharp fragments, and the gravel shows slight horizontal stratification. On the crest of the hill, some 450 feet high, there is a weather-worn boulder, four feet in diameter, of a soft, coarse, brown sandstone of Bryn Mawr age, apparently in place.

A fourth, precisely similar exposure of gravel with conglomerate, and at about the same elevation, caps the hill back of Media, near the Rosetree.

Without describing any further exposures, it already appears that in these elevated patches of ancient gravel we have the last remnants of a once continuous formation. The very great erosion which has swept away all but these few traces is a sufficient proof of its age. There are no points at all approaching the elevation of these hills, between them and the Atlantic Ocean; and it is at once suggested that these patches are the remnants of an oceanic deposit, possibly of Tertiary age. It is interesting to find that a precisely similar formation caps some of the hills in New Jersey. On top of the hill at Mount Holly, N. J., is an identical conglomerate and gravel, similar in appearance, and composed of the same materials as the formation in Pennsylvania. The conglomerate has the peculiar ferruginous glaze already noticed. It here overlies cretaceous marls and sands.

The Bryn Mawr gravel caps numerous high hills in Delaware county, and in northern Delaware increases largely in extent, covering the gneiss hills in patches several miles in length. At a point two miles northeast of Wilmington it comes within a mile of the river. It is in many places five feet deep and is less eroded than in Pennsylvania. As in Pennsylvania, its pebbles are mostly of sandstone and quartzite, and fragments of iron conglomerate ore abundant. A similar formation occurs upon the heights of Georgetown, D. C., and continues through the southern States in the same relative position. It is probably of Tertiary age, and represents the outliers of portions of the gravelly shore line of certain oceanic deposits which, nearer the Atlantic, are more largely developed, but represented by clays, sands, and such other finer material as would be deposited farther from shore.

This region has been elevated over 400 feet since these deposits were laid down, a fact which may lead to a more precise estimate of their antiquity.

Recapitulating the various surface formations here distinguished as occurring at Philadelphia we have, beginning with the most recent:

Formation.	*Geological Age.*
Recent alluvium.	Modern.
Trenton gravel.	Post-glacial.
Philadelphia brick clay.	Glacial.
Red gravel.	Glacial.
Yellow gravel.	Pre-glacial.
Bryn Mawr gravel.	Tertiary.

In these six deposits is written the ancient history of the Delaware valley. If we read the record aright, they tell us that, long ago, before man was created, when strange mammals roamed abroad, and when all southern New Jersey lay deep beneath the Atlantic, the waves of the ocean broke upon the hills of Bryn Mawr, Chestnut Hill and Media. At the same time, an inlet from the sea extended over a great part of the Montgomery county limestone valley, depositing clays holding extensive beds of iron ore. This region, then 450 feet lower than now, was afterwards slowly upheaved, and as the waters retreated, the yellow gravel was probably formed. Afterwards, and perhaps in consequence of this rise, the climate grew colder, and glaciers crept down from Greenland and Labrador, forming a huge *mer-de-glace* thousands of feet in thickness, which advanced to within 60 miles of Philadelphia. Again the land descended 175 feet lower than it now is, and again the waters covered the city. This time it was fresh water of icy coldness, bearing great icebergs, which stranded on the shores formed by the hill at Wayne Junction, Belmont, George's Hill, Hestonville, Haddington and Swarthmore. At this time the river Delaware was 10 miles or more in width, nearly 200 feet deep, and, as a roaring flood, deposited the red gravel and left in it the records of its waves. As the flood became more quiet, though still filled with mud derived from the base of the glacier, the brick clays were laid down, the floating ice floes meanwhile dropping their far carried boulders all over our city.

After many thousands of years, the "Great Ice Age" at length came to a close, the land rose to about its present level or somewhat higher, the waters retreated, and finally, as sudden elevations of tem-

perature thawed the glaciers still remaining in the head waters of the Delaware, there came those last great floods which deposited the "Trenton gravel." The Delaware, then so wide as to submerge most of Trenton, all of Bristol, and the river front of Philadelphia nearly up to the State house, was again filled with floating icebergs. The walrus played in its waters, while the reindeer and the mastodon roamed on its banks. Man also then first appeared With habits most probably like those of the Esquimaux, living in most primitive ways, he hunted and fished on the banks of the swollen Delaware, and occasionally dropped into the water his rude stone implements, long afterward to be found to tell the story of their makers.

Finally, the land began the sinking which is now in progress, the climate grew warmer, the Red Indian was introduced, and the modern era began.

This, in brief, is the tale told by our clays and gravels, Surely the long despised cobble-stones of our ill-paved streets become more worthy of our respect when we know their story. Still more interesting do they become when we learn that they can tell us of the early history of our own race. They belong to the "Trenton gravel," and we have already spoken of the relation of that formation to the *Antiquity of Man* on the Delaware. It now remains to point out more exactly what that relation is.

(To be continued.)

Production of Sulphur in the Soil of Paris.—Some recent excavations for public works, in Paris, have opened masses of mixed rubbish in which there is an abundance of native sulphur. Its crystallization can be perceived by the naked eye, and the microscope shows that the crystals are octahedral, with the usual forms of natural crystals, sometimes truncated and combined with right prisms. Daubrée attributes the origin of the sulphur to the simultaneous presence of sulphate of lime and organic matters which are associated with it, such as vegetable remains, manure, leather, and fragments of bones. In some places the quantity of sulphur is sufficient to pay for mining. It consists of a breccia of small fragments, incrusted with crystalline sulphur, which helps to cement them together. Crystallized sulphur is also produced between fibres of decayed wood. When the bed was opened it exhaled a powerful odor, resembling that of phosphorus, which was attributed to phosphuretted hydrogen.—*Comptes Rendus.*

KENNEDY'S REMOVABLE-SEAT STEAM VALVE.

At the stated meeting of the Institute held February 21, 1883, the Secretary exhibited and explained for the manufacturers (McCambridge & Co., Philadelphia) the above-named invention, which may be concisely described with the aid of the cuts, as follows:

Fig. 1 represents a circular metallic cage, in the bottom of which the valve seat is cut; this is the removable seat, and constitutes the

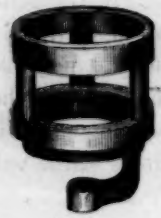


Fig. 1.

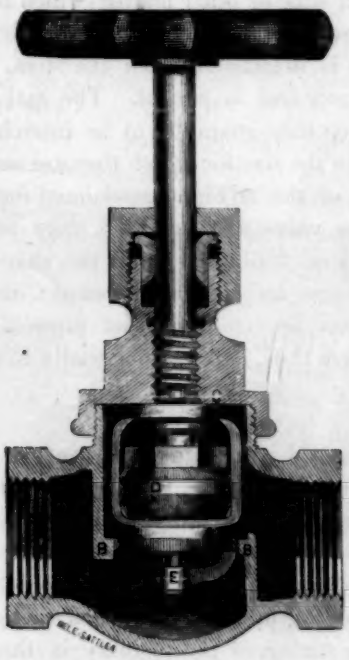


Fig. 2.

principal feature of the improvement. The prong (*E*) extending from the bottom of the cage and seat is a guide through which the stem in disk works; it insures the disk coming squarely upon the seat, and is very convenient for regrinding.

Fig. 2 represents an ordinary steam globe valve, with this modification attached. (*BB*) represents a flat seat cut in the body of the valve upon which the bottom of the cage (*A*) rests; the cage (*A*) is held in this position by means of the cap (*C*), which screws down upon

its top face, holding it as firmly as though it and the body were one casting. The bottom of the cage (*A*) and the seat in the body (*BB*), upon which it rests, are true surfaces, which, when pressed tightly together, as described above, form a tight joint, and as the cage always remains stationary after being put in place there is consequently no wear between them, so that when it becomes necessary to take out an old cage, to put in a new one, or regrind the seat in the old one, the seat in the body (*BB*), upon which the cage rests, will be found quite unworn; care should be taken, however, to see that this seat is entirely free from scale or other matter (which may have fallen upon it during the removal of the old seat), before dropping the cage upon it. The disk (*D*) is detachable from the stem, and must be duplicated each time a new seat is put in. The makers furnish duplicate seats and disk which they guarantee to be interchangeable, and to fit accurately any valve the size for which they are made.

Some of the advantages claimed for this valve are the following: That the valve seat and disk may be removed at will, and either reground or duplicated; that the valve is virtually a new one each time the seat and disk are renewed; and that the body of the valve need never be removed from pipes to repair or renew seat; all of which save time, and add materially to the usefulness of the valve.

Descartes and the Barometer.—Prof. L. Nourisson has read to the French Academy a memoir upon the relations between Pascal and Descartes. Twelve years before Torricelli performed his experiment, Descartes wrote as follows: "Air is heavy; it may be compared to a huge mass of wool, which surrounds the earth; the weight of this wool, pressing upon the surface of mercury in a cup, and not acting upon the surface of the mercury in the tube, prevents the mercurial column from descending. This weight is limited, and it does not prevent the descent until the weight of the column is less than its own. In order to detach the mercury from the ceiling of the tube, a greater force is required than that which is represented by the weight of the wool, or, in other words, of the air. The force which depresses the column of mercury is its own weight; the weight of the column which is elevated above the level of the cup is, therefore, equal to the weight of the air upon a portion of the surface of the cup equivalent to the surface of the column in the tube."—*Comptes Rendus.* C.

THE HALL TYPE-WRITER.

[From the Report of the Secretary, March 21, 1883.]

The machine herewith illustrated by a perspective view and two sections, represents a new and much simplified form of type-writer, invented by Thomas Hall, and made by the Hall Type-Writer Company of New York. The machine is very compact, and the mechanism by which its work is performed is quite ingenious.

The machine is enclosed in a box 17 inches long, 7 inches wide, and 3 inches deep, and as the total weight is only 5½ pounds, it will be seen that it is very portable. The perspective view gives a fair idea of the apparatus, when standing on a table, with the box opened, and

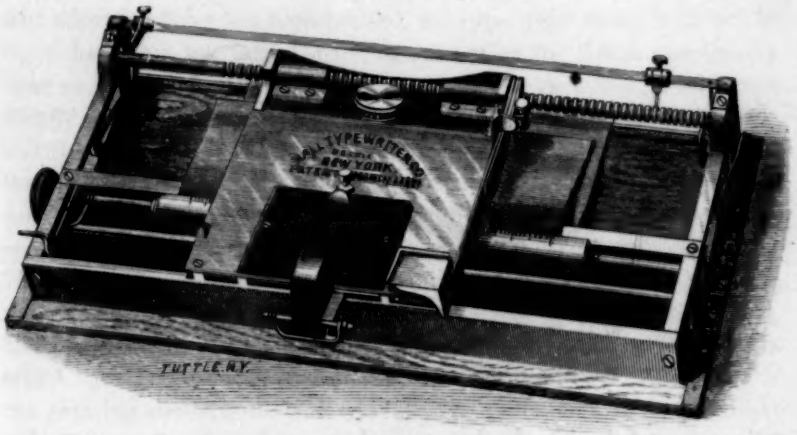


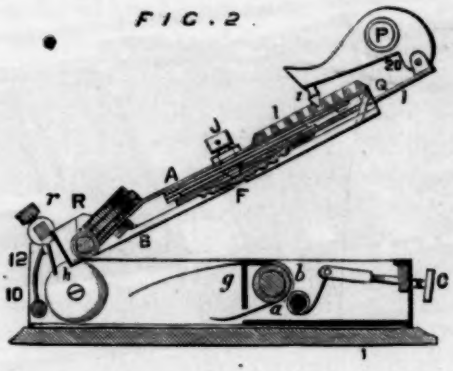
Fig. 1.

ready for work. The mechanism is carried upon a light bar frame, nickel-plated, hinged to the bottom of the box in front, and provided with pivotted bars at the back, the lower ends of which fit into serrated catches attached to the bottom of the box, so that the frame can be set at any convenient angle for working.

There are two distinct series of motions to be provided for: those affecting the paper, and those required for operating the type. The paper receives no lateral movement, that being provided for in the type mechanism, but it has to be fed upwards at the end of each full or broken line of printing, through a distance suitable to preserve the distinctness of the lines. Between the end bars of the frames and

towards the front of the apparatus is a spindle, enlarged for the greater part of its length so as to form a roller (*b*) Fig. 2, which is covered with india-rubber, as shown. On the left-hand side of the frame this spindle terminates with a small milled wheel, by which the roller can be turned at will. Immediately in front of the roller, and embracing it for its whole length, and for about one-third of its circumference, is the curved plate *B*, made very thin, nickel-plated, and graduated along its upper edge for a purpose to be presently described. The lower edge of this curved plate is fastened to the bar *a*, Fig. 2, parallel to and placed below the centre of the roller. The paper, which may be of any width up to 14 inches, and of any length, is held between the rubber face of the roller and the curved plate; the latter can be adjusted so as to increase or diminish the grip. This is effected by a light

FIG. 2.



spring connected with the bar *a*, and the stud and set-screw *C*; by lifting this latter *a*, the bar can be turned slightly round, and the plate *B*, moved from the roller. As soon as the lower edge of the sheet of paper is introduced between the curved plates and the roller, turning the milled disk *W* brings it forward into the position shown in the drawings, and printing may be commenced in any part of the sheet. We may assume, however, that it is intended to begin at the top left-hand corner, in the usual manner. To do this the sheet is fed forward by turning the milled disk and roller, till the desired margin is left at the top. As soon as one line has been printed, or whenever it is desired to commence a new line, by turning the head *W* a new surface of the paper is presented. It is obvious, however, that unless care were taken to turn the roller each time through a fixed distance,

the space would be irregular, and the appearance of the work untidy. To secure a uniform feed and therefore regular spacing, the lever *L* at the left-hand side of the machine is introduced. By pressing the thumb-piece at the end of *L* upwards, the roller *a* is caused to move through a certain distance, by the action of a spring coiled round the spindle of the roller, and connected to the lever *L*, and the angle frame *g* (Figs. 1 and 2). Stops above and below limit the travel of this lever. For spaces of varying widths which may be occasionally required, the milled disk *W* might be easily graduated, and set by means of a fixed pointer.

We have now to consider the more complex mechanism for producing the printed characters on the paper. As the latter does not move laterally, it is evident that the form must have such a motion, that after one letter has been printed, the type must travel from left to right through a determined space, so as to bring the letters successively over an unprinted part of the sheet. As every one knows, some letters occupy more space than others; thus I i occupy less room than M m, and the difference is greater in small, or "lower case" letters, than in the capitals. In the Hall machine the space for each letter is equal, for the eye very rapidly becomes accustomed to the apparent irregular spacing, and the simplicity of the machine is very greatly increased. Having impressed one letter, then, on the paper, the type traverses towards the right through a fixed distance—one-tenth or one-twelfth of an inch—and so on till the end of the line is reached. The way in which this is accomplished should now be described. The whole of the printing mechanism is carried by the carriage A (Fig. 2) hinged at the top to the rod *R*, and resting at the bottom on the front bar of the frame. The perspective view shows this arrangement clearly, and Fig. 2 indicates the mechanism; in this figure the carriage *A* is shown raised in position to show the printing. The rod *R* is held fast in suitable brackets at the top of the frame. For the whole of its length, excepting a short distance on the left, this rod is cut out in circumferential grooves so as to form a rack, The broad hinges attaching the plate *A* slide freely over the rod, but are very carefully fitted, so that there is no shaking, which would interfere with the regularity of the printing. Near the top of the carriage and in the centre of its width is a small circular box, with teeth around its circumference, and containing a coiled spring; the teeth engage in the grooves of the rod *R*, and tend to move the carriage. Suppose that the latter has traveled

along bar to the right-hand extremity, then by pressing a lever, the carriage can be pushed back by hand to the left-hand end; but this operation coils up the spring in the box, and secures a sufficient motive power to traverse the carriage from left to right for the whole length of the machine. In this way the forward travel is obtained, but it is evident that the movement must not only be intermittent, but must be normally limited to one tooth of the rack on the bar *R*, equal to the width of the spaces between the printed letters. The device by which this is effected is simple and ingenious; it is indicated in the perspective view, but requires a separate diagram to make it quite intelligible. On the right-hand side of the carriage A is a flat lever pivotted to and near the top of the plate by a pin, the head of which projects. Pinned to this lever, and lying close beside it, are two other shorter levers, one of which is a spring always tending to open. At their upper ends both of these levers have a semicircular recess, the diameter of which corresponds with that of the grooves in the rack bar *R*. The end of the long lever first mentioned has also a similar semicircular recess, which in its normal position is just clear of the lower half of the bar *R*, the two short levers pinned to it engaging in the upper half of one of the grooves; in this position the carriage *A* is held firmly. If the long lever is depressed by touching the finger-plate *S*, the upper end of the lever is raised, and the semicircular recess engages in one of the grooves on the under side of *R*, which locks the carriage; at the same time the two short levers pinned to it, are raised clear of the groove. Now the projecting stud on which the long lever turns, passes through a hole in the outer short lever which, as already said, is formed of a spring. As these levers are pinned to the long lever, it follows that the depression of the latter raises the short levers, but the instant that the spring lever is clear of the bar *R*, it flies open, against the stop *A* (Fig. 1). The coiled spring, however, in the box on the carriage cannot force the latter forward because it is locked by the end of the long lever engaging in the bar *R*. As soon as the lever is released, however, its end falls clear of the bar, and the coiled spring then forces the plate forward, the two short upper levers falling into the next groove, and locking the carriage again. The stop against which the spring lever presses, and just referred to (*A*, Fig. 1), is adjustable, so that the carriage can travel through one or two spaces, or not travel at all. The long lever, with the finger plate *S*, is used to produce the spaces between the words; precisely the same result is obtained by depressing the top plate of the

carriage, to which the system of levers is attached; this forms the spaces between the letters. In this way the carriage travels intermittently from left to right of the machine, either across the whole width of the paper, or for any distance that may be desired. In order to return the plate to the left-hand side, all that is necessary is to press a thumb-piece on the inner short lever, and a similar thumb-piece fast on carriage; this raises the upper ends of the short levers free of the grooved bar, and the carriage is then slid backward, the movement winding up the coiled spring; a new line may then be commenced, care being taken to feed the paper up through one space by lifting the lever *L*.

The printing mechanism is all contained in the carriage *A*. It consists of an upper and lower plate about three-eighths of an inch apart;

1	2	3	4	5	6	7	8	9
(	&	;	"	—	?	%	$	)
K	B	F	G	N	I	A	S	Q
J	C	D	O	E	H	T	W	V
X	M	Y	L	.	R	U	P	Z
k	b	f	g	n	i	a	s	q
j	c	d	o	e	h	t	w	v
x	m	y	l	,	r	u	p	z

the lower one is rigid, resting on the front bar of the frame, and connected to the rod *R* by brackets, on which it is free to turn, while the upper one is also hinged to the rod, as shown in the perspective view, and is held up from the bottom plate by levers fixed to a small shaft on the front of the upper plate, which is acted on by a spiral spring just strong enough to lift the plate, two spring latches fixed to the lower plate keeping it, however, in position. To the top of the upper plate is screwed a rectangular piece of ebonite, 3 inches long by 2¼ inches wide, in which are pierced seventy-two tapered holes, each hole corresponding to a type character. There is also a stud *J* about the middle of the plate and projecting through it on both sides. The printing characters are all raised in relief on a thin elastic plate of vulcanized rubber about 3 inches square, and stiffened around the edges by a light brass frame. The arrangement of the letters is such

that those most frequently used may come most easily to hand. The above diagram shows the extent and arrangement of these characters.

A variety of these forms, which can be fixed with very little delay, are manufactured, so that any class of type may be employed suitable for any language. They are attached to an articulated frame, shown in Fig. 3, which is a plan of the underside of the top plate A. This frame, which constitutes a parallel motion, has its fixed points at 16, 16, and is free to move in any direction with equal facility, and in such a way as to bring a character exactly beneath the stud *J* in the plate *A*. Fastened to the frame carried by the parallel motion is the key *P*, hinged, as shown, by a pin to the plate *1* (Fig. 2), going off to the frame just alluded to, and to which the form is attached. At the end

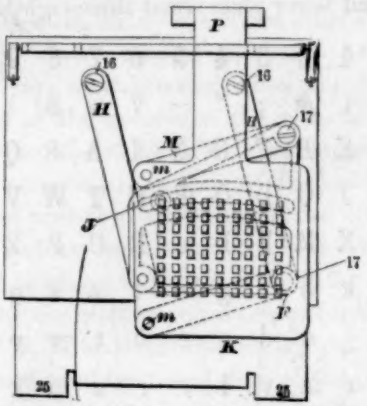


Fig. 3.

of the key *P* is a nipple *i*, which fits the holes in the ebonite plates, but does not go to the bottom of them. If, then, this nipple be placed in the hole belonging to the letter, F, for example, the movement necessary to bring the key to this hole, also by means of the parallel motion, brings the letter F on the india-rubber form, immediately under the stud *J*, and immediately over a small square hole in the lower plate of the carriage *A*, through which the paper is exposed. Then, if the key *P* be depressed, the upper plate of the carriage *A* is is also depressed, and the letter F is brought into contact with the paper. The upper surface of the bottom plate of the carriage *A* is covered with an inking pad, and it follows that when the top plate is depressed all the characters in the form are brought in contact with the inking pad, except F, the ink from which is transferred to the paper.

The same action of depressing the plate sets in action the intermittent feed already described, and when the plate rises, the carriage *A* moves to the right, the space of one letter, and a blank piece of paper is again exposed through the small square opening in the bottom plate of the carriage. When the end of a word is reached the operator depresses the spacing lever by touching the finger-plate *S*, and the carriage traverses the necessary distance. The bed on which the paper rests to receive the impression is formed of the angle bar *g* (Fig. 2.), which runs between the end frames immediately behind the roller *b*.

Two more points connected with this extremely ingenious machine remain to be noticed; the first refers to the device for regulating the length of the lines. Above and behind the rack bar *R*, is a square grduating rod running from end to end of the type-writer. On this slide two stops that can be set in any position by set screws. The right-hand stop is provided with a tail rigid in one direction, but free laterally. On the back of the carriage *A* is a finger, and when this comes in contact with the tail just mentioned, the latter rises, giving the square bar a partial turn on its axis, until the contact ceases by the passage of the carriage, when the bar actuated by a spring returns to its normal position, and in doing so stikes a bell, and thus notifies that the end of the line is reached. The second point refers to the means provided for going back to any place on the line to make a correction. The square bar just alluded to is graduated, and the curved plate clipping the paper is also graduated to correspond, so that if the pointer on the top left-hand side of the carriage be set at the same division as that opposite any letter to be corrected, the form is brought back to the exact spot.

The machine permits the work to be inspected at any time by lifting the carriage *A* without letting go of the handle *P;* a great variety of characters can be employed, and the use of only one key renders the manipulations easily and quickly acquired, for a speed of thirty to fifty words a minute. The workmanship, as is absolutely necessary for mechanism of this class, is excellent.

Sire's Pendulum.—M. Sire has presented to the French Academy a modification of Foucault's pendulum, which accurately exhibits the laws of displacement in whatever latitude the experiment may be tried.—*Comptes Rendus.* C.

Book Notices

THE MATERIALS OF ENGINEERING. In three parts. Part I. Non-Metallic Materials; Stones, Timbers, Fuels, Lubricants, etc., by Robert H. Thurston, A. M., C. E., etc., etc. New York, John Wiley & Sons, 15 Astor Place, 1883.

That eminent mechanic, James Naysmith, defined *Engineering* as "Common Sense applied to Materials," and although the definition is broad rather than accurately descriptive, it suggests in a forcible manner the necessity which requires of the *Engineer* a thorough knowledge of materials, their nature and capabilities. In the practice of his profession he operates on materials, and the laws of physical science are the tools with which he works. He is ever on the alert to add to his knowledge of the characteristics of these materials, and eagerly grasps each new fact that is presented to his notice. In the book now before us, the first volume of the series, Prof. Thurston presents carefully arranged and thoroughly indexed a vast amount of useful information concerning the various non-metallic substances with which the engineer may have to do, and incorporates in his pages the latest investigations of many observers.

Chapters I, II, and III, give in a compact form a general description of all the chief varieties of building materials comprised under the heads—stones, cements, and timber—and states the principal localities from which they are each obtained, their physical peculiarities, the uses to which they are each especially adapted, the proper method of preparation, etc., etc. Very full tables are given of strengths of masonry, brickwork, and the different kinds of wood used in construction. The various kinds of masonry are described and illustrated, together with many cements and mortars. The strength of timber is treated at length, considerable space devoted to the various methods that have been adopted for preserving wood, and the subject concluded by a valuable table giving at a glance the special adaptations of the various kinds to the uses of the carpenter, the ship builder, and the millwright; and also a classification of special properties showing the woods grouped under such heads as stiffness and elasticity, toughness and strength, etc.

The many varieties of Fuels are treated in Chapter IV, the physical and chemical characteristics described, relative efficiency of various

fuels and furnaces discussed, and the general principles governing economy in combustion set forth.

Chapter V contains in an abridged form the gist of Prof. Thurston's treatise on *Friction and Lubrication.*

Chapter VI covers a collection of useful facts concerning such topics as Leather Belting, Paper, India Rubber, etc., and the remainder of the book is made up of a brief description of the metric system, followed by a number of tables for the comparison of metric with U. S. standard weights and measures. The "Centimetre—Gramme Second" system of Units, is also described and a short table of four figure logarithms is given.

If this book is justly open to any criticism, it is perhaps that these complete metric tables, etc., which occupy nearly one-sixth of the entire number of pages, cannot be strictly included under "Materials of Engineering," and in fact would be more serviceable in an engineer's "pocket-book," or in a separate binding rather than as an appendix to such a volume as the present. It may also be questioned whether the practice, rigidly adhered to, of giving all dimensions in terms of the metric scale as well as in English equivalents, does not increase the bulk of the volume without giving any commensurate advantage, especially as convenient conversion tables are now so common. These are, however, merely matters of individual preference, and we are none the less indebted to the author for another valuable addition to the Engineer's library.

Modification of Electrodynamic Energy by Terrestrial Motion.—J. Frölich finds by experiment that the mutual influence of two currents is not fully expressed by Grassmann's law, but that it is also somewhat dependent upon the hour of the day. He also finds that many of the electrodynamic laws which have been hitherto accepted involve a theoretical assumption that the conductors and the free electricity are referred to the earth in a hypothetical state of absolute rest. Clausius, in a late pulication, has recognized the importance of Frölich's views, and Rowland's investigations require a consideration of the earth's motion for a satisfactory interpretation—*Wied. Annal.* C.

[The relations of electricity and magnetism to cosmical motion were discussed by Chase, in the proceedings and transactions of the American Philosophical Society for 1864.]

Microscopic Inscription of Physiological Movements.—M. Marey has invented an instrument which enables him to make an exact record of the phenomena of circulation, respiration, and muscular and nervous actions. By employing a fine steel point and a thin layer of lampblack, movements which do not exceed one-tenth of a millimetre ($\frac{1}{250}$ in.) are magnified to great dimensions. The apparatus can easily be carried in the pocket.—*Comptes Rendus.* C.

Elasticity and Electric Conductivity of Coal.—W. Becty reports a series of experiments upon some cylindrical sticks of coal prepared by Carré, estimating their modulus of elasticity by determining the note which is produced by rubbing them longitudinally with rosined fingers. All the observations showed an increase of conductivity with increase of temperature. He does not think that coal, whether compressed or prepared from gas coke, is so homogeneous as Siemens supposes, but its texture is sufficiently uniform to furnish conclusive evidence of the relations which he has pointed out.—*Ann. der Phys. und Chem.* C.

Thermal Theory of the Galvanic Current.—J. L. Hoosweg finds that there is always an evident decomposition, when the thermo-electric equivalent of electrolysis exceeds the electromotive force of the battery. He deduces from his experiments the following conclusions: 1. Every manifestation of electricity is a consequence of the disturbed thermal currents, at the point of contact between two heterogeneous bodies. 2. Electricity is propagated either through conduction or dielectric radiation. 3. Bodies may be divided into dielectrics and adielectrics. In the first the conductivity increases, in the second it diminishes, with an increase of temperature. 4. An electrolyte is a decomposible dielectric. 5. In every closed circuit, of which a portion is dielectric, the sum of the potential differences is either greater or less than zero. 6. The galvanic current arises at the expense of the temperature at one point of contact and produces an increase of temperature at the other. 7. The electrolytes in the circuit are always decomposed. Hence arise new differences of the potential, which may diminish the previous sum or even reduce it to zero, through chemical polarization. 8. The change of temperature is estimated by the galvanic heating, the production of warmth at the points of contact, and the chemical heating. These changes lead to thermal polarization. —*Ann. der Phys. und Chem.* C.

Cause of Weakness in the St. Gothard Tunnel.—Investigations have been made of the cause of weakness in the parts of the St. Gothard tunnel where the vaults were crushed, and it is thought that the accident must be attributed to the action of damp air upon the schists and gneiss, and to the decomposition which resulted therefrom; the presence of anhydrous sulphate of lime, or karstenite, was also an important agency; its transformation into gypsum is followed by a disaggregation which renders the rock incapable of sustaining its pressure. Other hypotheses have been framed, but M. Loustan considers this as the most plausible.—*C. R. de la Soc. des Ingin. Civ.*

Dust, Mist, and Clouds.—Mr. Aitken draws the following conclusions from an extensive series of experiments: "Whenever vapor condenses in the atmosphere, the condensation is always made on a solid nucleus, which is furnished by particles of dust. Without dust there would be neither mists nor clouds, and the super-saturated air would transform every object upon the earth's surface into a condenser upon which it would deposit its excess of water. Whenever the breath becomes visible in a cold atmosphere it demonstrates the impure and dusty condition of the air. The foam of the sea, meteoric matter, and fires are fertile sources of the dust and impurity."—*Les Mondes.* C.

South American Woods.—M. Thanneur describes some varieties of South American wood which seem likely to become valuable for engineering purposes. The yandubay is exceedingly hard and very durable. The couroupay is also very hard and very rich in tannin. It bears some resemblance to the quebracho, which is perhaps the most interesting of all and the most used. It is very abundant in Brazil and La Plata. Its diameter varies within the same limits as that of the oak, but the trunk is shorter. It is used for railway sleepers, telegraphic poles, piles, etc. It is very durable, especially when well seasoned. It is much heavier than water, its specific gravity varying between 1·203 and 1·333. Its color is reddish, like mahogany, but it becomes darker in time. On account of its hardness it is difficult to work, and it cannot be readily cut with an axe. It has been introduced into France on account of its richness in tannin. A large portion of the Brazilian leather is tanned by the sawdust of quebracho, but the leather is rather brittle. A mixture composed of one-third of powdered quebracho and two-thirds of ordinary tan gives very good results.—*Ann. des Ponts et Chauss.* C.

Mariotte's Law.—Amagat's various experiments upon the compressibility of gases, show that the belief that a gas continues to vary from Mariotte's law by becoming less compressible as the temperature continues to be increased, is not correct. If hydrogen were cooled sufficiently it would finally be compressed more than the law indicates; on raising the temperature the variation from the law would first vanish and then become negative; but this variation, instead of continuing to increase negatively, would attain a maximum and then begin to approach unity.—*Ann. de Chim. et de Phys.* C.

Mean Temperatures of the Northern and Southern Hemispheres.—Hennessy called attention, more than twenty years ago, to the superiority of water over the other materials of the earth's surface, for the absorption and diffusion of solar heat. His conclusions were diametrically opposed to those which had been previously adopted, but they have gradually commanded the increasing support of observers. W. Henel has therefore published the conclusion, that the difference of temperature between the two hemispheres is very small, and that the southern hemisphere, which has the larger mass of water, also has the higher temperature. M. Hann has given a summary of observations, in the *Comptes Rendus* of the Vienna Academy, and he concludes that 15·2° (59·4F.) is the temperature of the two hemispheres.—*Comptes Rendus*, xcv, 471. C.

Influence of Minute Mixtures.—The presence of $\frac{1}{30000}$ of a pound of antimony in a pound of melted lead increases the rapidity with which the lead oxidizes and burns. Lead which contains more than $\frac{1}{14000}$ of its weight of copper, is unfit for the manufacture of white lead. Gold with an alloy of $\frac{1}{2000}$ of lead is extremely brittle. Copper with $\frac{1}{2}$ per cent. of iron has only 40 per cent. of the electric conductivity of pure copper. Nickel was regarded as a metal which could be neither rolled, hammered nor welded, until it was found that the addition of $\frac{1}{1000}$ of magnesium, or of $\frac{3}{1000}$ of phosphorus, makes it malleable. Some varieties of cast steel are exceedingly brittle, but the addition of $\frac{1}{12}$ of one per cent. of magnesium makes them malleable. At the Paris Exposition of 1878, a great difference was found in the toughness of sheets which were made of Swedish puddled iron. The only difference which chemical analysis showed was, that the good plates contained $\frac{29}{10000}$, and the bad $\frac{31}{100000}$, of phosphorus.—*Der Techinker.* C.

Newton's Rings.—Sohncke and Wangerin have repeated and extended their observations upon Newton's rings, with results which confirm their early views with regard to the slight eccentricity of the rings. If the microscope is so placed as to give the sharpest possible definition to any portion of a dark ring, in order to see another ring, or even another part of the same ring, it is not sufficient to move the microscope in a parallel plane, but it must be elevated upon one side and depressed upon the other.—*Ann. der Phys. und Chem.* C.

Treatment of Copper in the Bessemer Converter.—P. Manhès, of Lyons, has successfully applied the Bessemer process to the treatment of copper ores. M. Gruner states that the method has reduced the metallurgical labor from six or eight operations to three, and although he does not anticipate so radical a revolution as in the production of steel, he does not hesitate to predict a brilliant future. In France, especially, where fuel is dear, the process will utilize ores which have hitherto been worthless. The progress is the more remarkable, because the metallurgy of copper had remained completely stationary for the last fifty years.—*Bull. de la Soc. d'Encour.* Sept. 1882. C.

Tones Produced by Intermittent Radiation.—W. C. Röntgen was induced, by Bell's experiments with the photophone, to employ an apparatus which he had long used in his physical lectures for showing the effects of intermittent radiation in gases. He used the lime light as a source of heat. The rays were concentrated by lenses upon a notched disk of pasteboard, which could be rapidly rotated about a horizontal axis. An absorption apparatus was placed behind the notches, with a short glass tube, of one centimetre diameter, over which was placed a wide caoutchouc tube that led to the ear of the observer. The rays penetrated into the absorption apparatus when openings in the disk came in front of the rock salt plate, and were interrupted by the unnotched parts of the disk. With air, hydrogen, or oxygen, he was unable to obtain any tones; but with illuminating gas and with ammonia distinct tones were heard, somewhat like the whistling of a moderate wind. The pitch varied with the velocity of rotation and the tone vanished only when the rotation became very rapid.—*Wied. Annal.* C.

New Analysis of Tobacco Smoke.—G. Le Bon, and G. Noel, have sent to the French Academy three vials, containing products which they have succeeded in extracting from tobacco smoke. They are: 1, prussic acid; 2, an alkaloid of an agreeable odor, but dangerous to breathe, and as poisonous as nicotine, since $\frac{1}{20}$ of a drop destroys animal life; 3, aromatic principles, which are as yet undetermined, but which contribute, with the alkaloid, to give the smoke its perfume. The alkaloid appears to be identical with collidine, which has been observed in the distillation of many organic substances, but its physiological and poisonous properties have been hitherto unknown.—*Comptes Rendus.* C.

Relation between the Major and Minor modes in Music.—F. Ricard has been experimenting with a key board of equal temperament, and finds that inversion changes the mode from major to minor, and *vice versa*. M. Corun, without adopting Ricard's views upon the constitution of musical scales, thinks that this curious inversion is worthy of study, and that it may throw some light upon the obscure questions relative to the interpretation of major and minor melodies.—*Comptes Rendus.*

[The "Orginnette" furnishes great facilities for experimenting on inversion. Some of the results are very curious, and if they are carefully investigated, they may lead to important scientific conclusions.] C.

Selenium as a Regulator of Heat.—P. Germain proposes to use the various degrees of resistance which selenium opposes to the passage of electricity at different temperatures and under different rays of the spectrum, to the regulation of the temperature, in muffles for enameling painted glass or porcelain. He uses a thermo-electric battery of thirty elements, which receives the heat directly from the muffle. The opposite pole is connected with the wall of a porous vessel, full of water, which maintains a sensibly constant temperature. The thermo-electric current increases in potential proportionally to the elevation of the temperature in the muffle. The selenium is brought into the circuit, but it remains comparatively unaffected until the muffle has reached the proper luminous temperature, when it allows the current to pass and to give a signal by means of a bell.—*Comptes Rendus.* C.

TO WHOM IT MAY CONCERN:

At a stated meeting of the Franklin Institute, held Wednesday, March 21st, it was

Resolved, That the President be authorized and requested to appoint, as early as practicable, a Committee to examine the several forms of apparatus used for projections upon the screen of illustrations of all kinds, for lectures, etc.; that the said Committee be requested to invite the co-operation of those interested in the manufacture and use of these instruments, to the end that they may be induced to offer their instruments for competitive tests in comparison with others; that the Committee have the permission to make use of the lecture-room of the Institute for their purpose on any evening when it is not engaged; and that they be requested to prepare a report embodying the results of their investigations, together with such recommendations respecting the construction and use of such instruments as they may deem proper to make.

The Committee appointed under this resolution have directed me to send a notice to the various parties known to be interested in the sale and exhibition of projecting apparatus, asking them to furnish this Committee with specimens of their instruments for comparative tests.

If you wish an examination made of your instruments, please notify.

Yours respectfully,

CHAS. M. CRESSON, M.D., *Chairman of Committee.*

No. 417 Walnut street, Philadelphia, April 5, 1883.

LIST OF BOOKS ADDED TO THE LIBRARY DURING JANUARY, FEBRUARY AND MARCH, 1883.

Academie Royale des Sciences, etc., de Belgiques. Annuaire, 1883. Presented by the Academy.

Adjutant-General of Pennsylvania. Annual report for 1882. Harrisburg, 1883. Presented by James W. Latta.

Allnutt, H. Wood Pavements. London.

Anderson, W. Manufacture of Gunpowder at Ishapore Mills in Bengal. London, 1862.

André, G. G. Rock Blasting. London, 1878.

Annales des Ponts et Chaussées. Personnel, 1883. Paris. Presented by the Publication Office.

Archæology and Ethnology, American. Fifteenth annual report of the Trustees of Peabody Museum. No. 2. Vol. 3. Cambridge, 1882. Presented by the Museum.

American Railway Master Mechanics Association. Report of proceedings of Fifth Annual Convention. Cincinnati, 1882.
Presented by the Association.

Army Register. Official; for January, 1883. Washington.
Presented by the Adjutant-General.

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E. HILTEBRAND, *Librarian.*

Franklin Institute.

HALL OF THE INSTITUTE, April 18, 1883.

The stated meeting of the Institute was held this evening at the usual hour, with the President, Mr. Wm. P. Tatham, in the chair.

There were present 120 members and 28 visitors.

The minutes of the last meeting were read and approved.

The Actuary submitted the minutes of the Board of Managers, and reported that at the stated meeting held April 11th, 14 persons had been elected to membership.

He also reported, by instruction, that at the same meeting the Board had adopted the following resolution: *Resolved*, "That the Committee on Exhibition be enlarged, and that the Committee be instructed to take measures to raise an adequate guarantee fund to protect the interests of the Franklin Institute in the contemplated Electrical Exhibition."

The special committee on the "Prevention of Fires in Theatres," presented majority and minority reports which were accepted, and referred to the Committee on Publication.

Mr. C. J. H. Woodbury, of Boston, then read a paper on a "Portable Electric Testing Apparatus," having for its object, to afford a convenient and reliable method of frequently testing the insulation of electric lighting circuits. Mr. Woodbury's paper has been referred to the Committee on Publication.

Mr. Wm. F. Goodwin followed with a paper on the "Goodwin-Roberts Locomotive," in which the special features of the new engine were shown with the aid of lantern views, by comparison with others of improved construction. Mr. Goodwin, claimed in his engine, to have overcome the difficulties raised by Mr. Wolf, at the previous meeting, in his remarks on Mr. Le Van's paper.

Mr. Hugo Bilgram, by request, thereupon described and exhibited in operation upon a lathe, a screw-cutting attachment, invented by Mr. A. Nacke, of Philadelphia. This device automatically releases the jaws of the screw-cutting attachment as soon as the screw has been cut, thereby greatly reducing the time required for cutting screws.

The Secretary's report included among others, a description of the following inventions:

The Continental Underground Cable Company's system of laying underground electric cables, consisting of a series of semi-circular pockets or troughs of sheet metal, contained in an arched chamber of any required size, the foundation and walls of which are made of bricks pressed from a plastic substance described as being strong, hard, and a good insulating material. The cables are laid in the troughs above named, being drawn through or removed by means of a carrier with a rope or chain, which may be run to and fro in the bottom of